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COVER STORY PAGE 4

Technological progress in large-format photomultiplier tubes at Super-Kamiokande

OPTO-SEMICONDUCTOR PRODUCTS PAGE 21

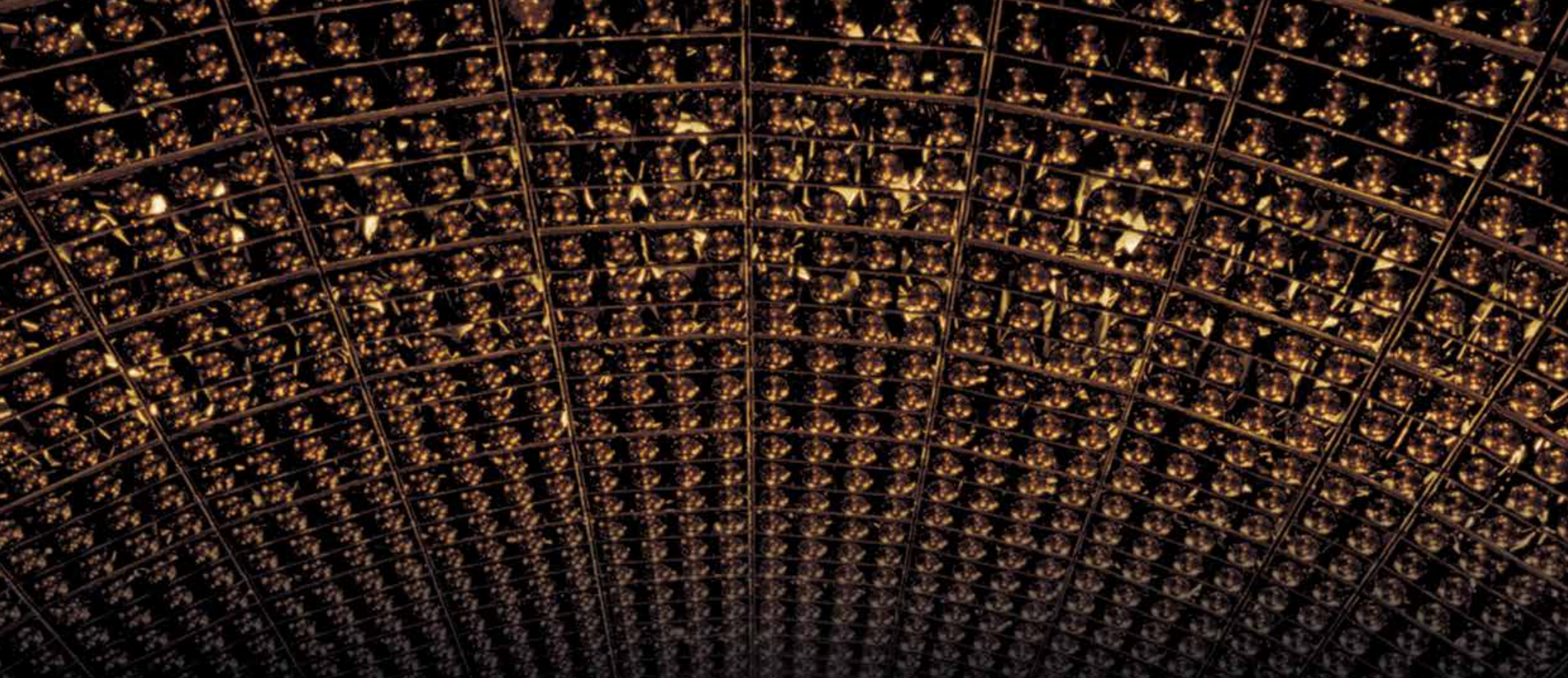
16 ch distance measurement APD array for direct TOF

ELECTRON TUBE PRODUCTS PAGE 24

LIGHTNINGCURE LC-L5G High output 10 W/cm^2

SYSTEMS PRODUCTS PAGE 39

A new NanoZoomer for whole slide imaging



Hamamatsu Photonics congratulates winners of the 2015 Nobel Prize in Physics

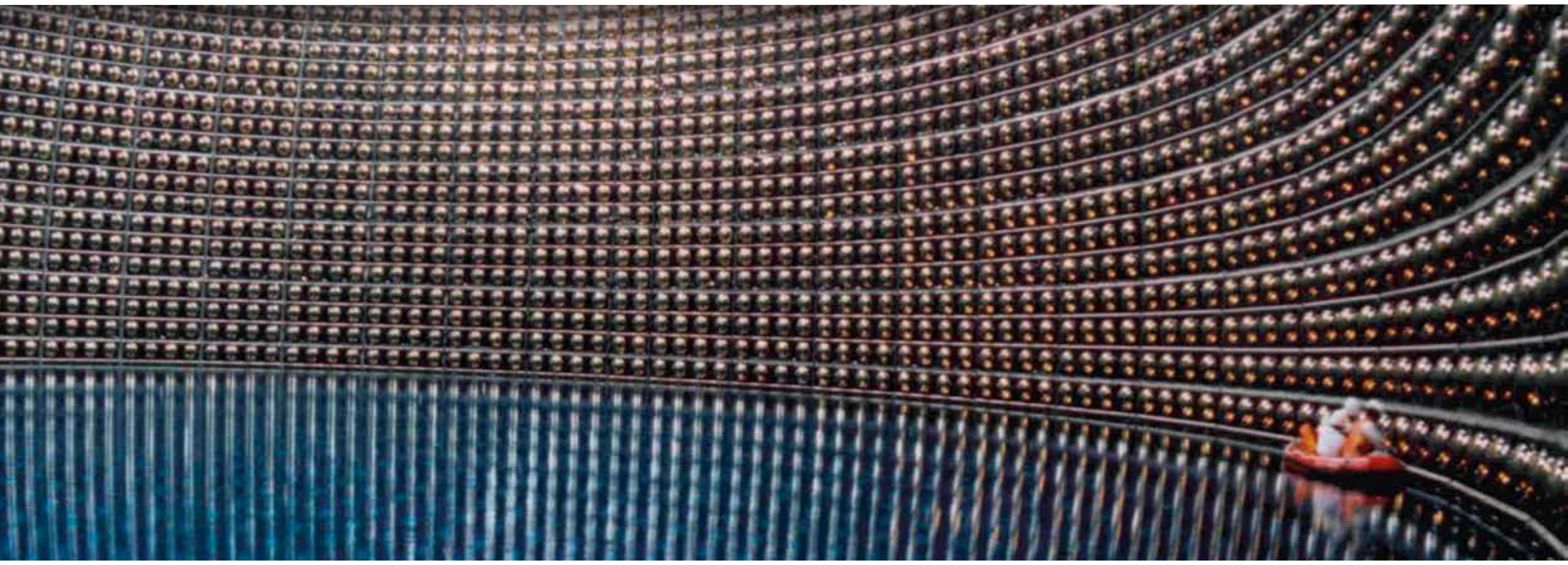
Hamamatsu Photonics K.K. would like to congratulate Professor Takaaki Kajita of the University of Tokyo and Professor Arthur B. McDonald of Queen's University (Canada) for being jointly awarded the 2015 Nobel Prize in Physics for the discovery of neutrino oscillations, which shows that neutrinos have mass.

Hamamatsu employees are especially delighted by the recognition of Professor Kajita, whose research at the Super Kamiokande was conducted in a large-scale facility that included photomultiplier tubes manufactured by the company’s Electron Tube Division. Professor Kajita was one of several top-tier physics researchers in Japan that provided feedback to Hamamatsu during the development of the high-performance 20-inch photomultiplier tube (R3600-05) that was installed at the Super Kamiokande facility to detect atmospheric and solar neutrinos. When observations at the facility began in 1996, there were 11,200 pieces of this photomultiplier tube installed in a 50,000-ton tank of pure water placed 1,000 meters underground. In 1998, when Professor Kajita announced the results of his observations at an international conference on neutrino astrophysics in Gifu Prefecture, his statement that “there is mass in neutrinos” was widely reported by news media in Japan. It is a source of great pride of Hamamatsu employees to have contributed to the discovery of new knowledge, as this is part of the company’s mission to continually support humankind’s journey of scientific discovery.

For further information contact us on email: europe@hamamatsu.de or visit our website: www.hamamatsu.com

Content

Cover Story



Technological progress in large-format photomultiplier tubes at Super-Kamiokande

Hiroyuki Kyushima, *Electron Tube Technical Department, Electron Tube Division*

Super-Kamiokande*1 is a neutrino observatory located in the town of Kamioka in Hida city, Gifu prefecture, Japan. Super-Kamiokande leads the world in research on studying the properties of neutrinos*2 by detecting the faint Cherenkov light*3 generated by neutrinos in the rare cases where they collide with water molecules. Super-Kamiokande drew a great deal of international attention when Professor Takaaki Kajita, Director of the Institute for Cosmic Radiation Research, University of Tokyo, was awarded the 2015 Nobel Prize in Physics, following the 2002 Nobel Prize in Physics given to Masatoshi Koshiba, Emeritus Professor of University of Tokyo.

This article tells of an episode when we developed the large-format photomultiplier tubes*4 used at Super-Kamiokande and also describes how the technology we invented at that time is applied to our current products.

Specs required for photomultiplier tubes at Super-Kamiokande

In July 1986 we talked with Professor Koshiba about the next planning (for the Super-Kamiokande facility) after Kamiokande. This was some 7 months before Kamiokande succeeded for the first time in human history in observing neutrinos arriving from the supernova that exploded in the Large Magellanic Cloud.

Professor Koshiba's new plan called for enlarging the pure water tank size about 20 times from 3,000 tons to 50,000 tons. However, this enlargement plan would cause a drastic drop in the number of photons reaching the tank wall, making it difficult to obtain a 50 centimeter position resolution equivalent to the diameter of one 20-inch photomultiplier tube. The specifications required by Professor Koshiba called for: (1) Obtaining pattern information for the Cherenkov light, (2) Time characteristics within 3 nanoseconds, and (3) Capable of clearly discriminating the peak of the single-photon pulse height distribution from the noise level that becomes relatively noticeable as the number of photons decreases. Improving these characteristics made it essential to boost performance by creating a new 20-inch photomultiplier tube.

Method for boosting performance of 20-inch photomultiplier tube

We studied how to detect even just one photon more reliably wherever that photon might hit the surface of the photocathode. Fabricating a smaller electron multiplier section makes it harder to focus photoelectrons from photocathode onto the electron multiplier section with an electron lens due to geomagnetic effects. On the other hand, making the electron multiplier larger creates another problem that the thin electrodes droop during fabrication due to thermal effects. There was also the issue of how to minimize the difference in response time of photoelectrons emitted from the center and from the periphery of the photocathode surface.

To achieve these goals, we designed a new dynode with a large surface area. More specifically, to improve the time characteristics of the venetian-blind dynode, we halved the dynode width (pitch) to 2.5 mm to obtain a scale effect. We also widened the electron multiplier aperture to 90 mm from its prior diameter of 75 mm to minimize the geomagnetic effects. Furthermore, in order to make the photoelectrons emitted from the photocathode enter the first dynode more efficiently, we found the optimal position relation between the first and second dynodes and also arranged a grid pattern immediately in front of the first dynode to match each blade of the venetian-blind dynode. Since photoelectrons are emitted from the photocathode surface formed on the inner surface of a semispherical glass bulb in response to the incoming photons, they are greatly focused on the first dynode by the curvature of the semispherical surface and further focused by the grid pattern onto each blade of the first dynode.

In this way we improved the time characteristics whilst simultaneously retaining the ability to clearly differentiate the peak of the single-photon pulse height distribution.

Three patents from the development process

Patent 1

Grid pattern placed immediately in front of first dynode
[Objective] Arrange a designated pattern for the focusing electrode (grid pattern) placed between the photocathode and the first dynode to focus photoelectrons by electron lens effect to efficiently guide photoelectrons from the photocathode to the first dynode.

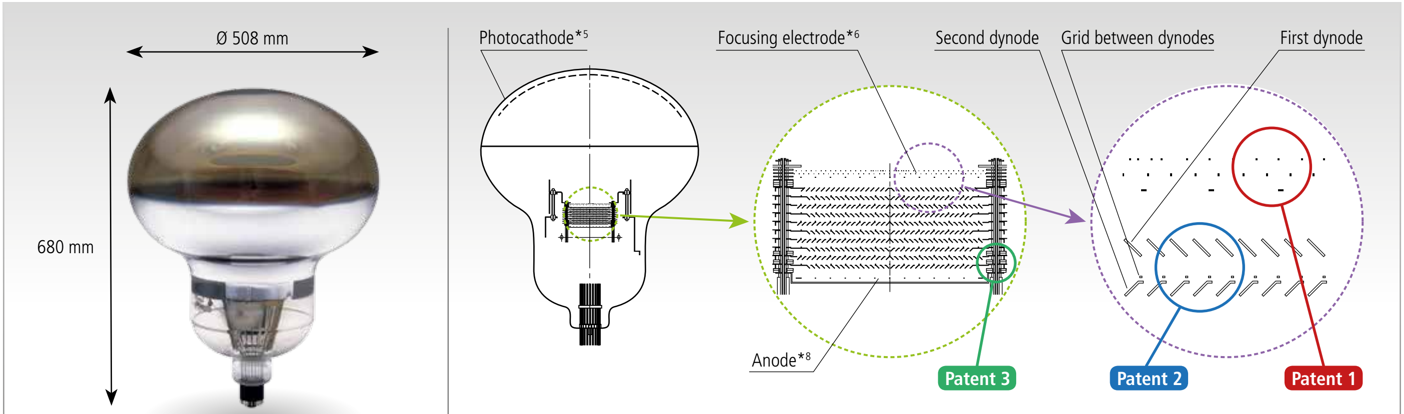
Patent 2

Optimized position relation between first and second dynodes
[Objective] Fabricate a secondary electron multiplier and a photomultiplier tube with good collection efficiency by correcting the trajectory of secondary electrons emitted from the first dynode to increase number of electrons reaching the second dynode.

Patent 3

Prevention of feedback to photocathode
[Objective] Prevent ions and weak light generated near the anode of the photomultiplier tube from feeding back to the photocathode by utilizing an optimal number of frame shaped insulated spacers in the electron multiplier section.

20 inch photomultiplier tube*4



Sectional view of 20 inch photomultiplier tube

Enlarged sectional view of electron multiplier*7

Enlarged sectional view of focusing electrode (grid pattern) and dynode

*1 **Super-Kamiokande:** World's largest water Cherenkov type neutrino observatory.
*2 **Neutrino:** A type of elementary particle having no electric charge and very rarely interacting with matter, which makes it extremely difficult to detect. The group led by Professor T. Kajita proved that neutrinos do have mass.
*3 **Cherenkov light:** Very faint bluish light emitted when charged particles pass through water at velocities close to the speed of light.
*4 **Photomultiplier tube:** A type of vacuum tube that functions as an extremely high sensitivity photosensor. A typical photomultiplier tube is comprised of a photocathode (photoemissive surface), focusing electrode, electron multiplier section, and an anode.
*5 **Photocathode:** A photoemissive surface that emits electrons (photoelectrons) when struck by light (photons) in a vacuum.
*6 **Focusing electrode:** Electrode designed to guide the photoelectrons emitted from the photocathode toward the electron multiplier.
*7 **Electron multiplier:** A secondary electron multiplier made up of multi-stage electrodes (called dynodes) capable of multiplying electrons 1-10 million times.
*8 **Anode:** An electrode that collects the electrons multiplied by the electron multiplier.

Cover Story

Episode

① Could not fabricate the electrode structure as designed
A problem occurred in which the mold for making the dynode blades to dimensions of a 2.5 mm width and 90 mm length was broken only after a few press-work cycles. To resolve this problem, the High Energy Accelerator Research Organization (KEK) made mold fabrication experiments. Then, the Hamamatsu-Electronic Press Co. Ltd. continued the development to fabricate a mold that splits in the center also by using several molds (2 cutting and bending processes, 2 forming and bending processes) and finally succeeded in making practical and hard-to-break molds with the stress applied to a single mold properly dispersed.

② Problem of a large noise level
The noise level drastically increased when a voltage of 1,000 V or more was applied. As a countermeasure to this problem, we interposed an insulating materials between the adjacent dynodes to prevent ions and light from feeding back to the photocathode in the electron multiplication process.

③ Dedicated manufacturing plant was needed
A dedicated factory was required in order to manufacture 11,200 20-inch photomultiplier tubes. We adopted a design using an easy-to-see, easy-to-understand counterclockwise process layout within the plant. Up until that time, the workers held a large photomultiplier tube in their hands while moving them, but in the new plant, photomultiplier tubes are moved by cranes and roller conveyors after the sealing process. The factory layout left in a room on the first floor of building No. 7 at the Toyooka Factory reminds us of the work at that time.

The neutrino has mass

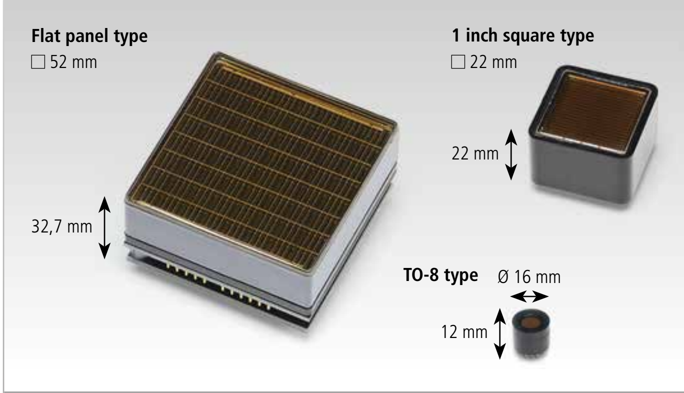
On June 5, 1998, Professor Kajita made the startling announcement that "The neutrino has mass" at the "International Conference on Neutrino Physics and Astrophysics" held at Takayama city, Japan. The conclusion that the neutrino has mass was reached from data found from observing atmospheric neutrinos over 2 years at Super-Kamiokande. This led to a push to reconsider the conventional "Standard Model" of particle physics.

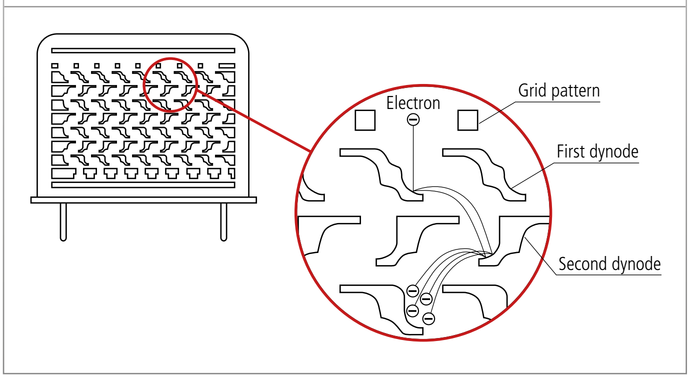
On June 19, 1999, in order to verify that neutrinos have mass by utilizing artificial neutrinos, an experiment called K2K (or KEK to Kamioka) was performed in which a large quantity of muon-neutrinos made at the KEK synchrotron (proton accelerator) in the city of Tsukuba were launched through the earth toward Super-Kamiokande some 250 km away. This was the first time in the world that artificial neutrinos were detected and this was verified by the detector at Super-Kamiokande.

Applying Super-Kamiokande technology (Technological continuity)

① Applying this technology to metal package photomultiplier tubes
The technology for placing a grid pattern immediately in front of the first dynode has been even further simplified and applied to metal package photomultiplier tubes developed in 1992. Moreover, the technology for optimizing the position relation between the first and second dynodes has been utilized to invent metal channel dynodes with no grid patterns, which can be mounted between each of the further evolved venetian-blind type dynodes. To obtain the same effect in preventing ions and light from feeding back to the photocathode without using grid patterns, the feedback prevention has been improved by minimizing the gap between dynodes and also by using metal packages.

Metal package photomultiplier tube





As a result, we developed the world's smallest (at that time) TO-8 metal package photomultiplier tubes that inherited the technology originally developed for the world's largest photomultiplier tubes to achieve a compact design with excellent time characteristics and the ability to clearly differentiate the peak of single-photon pulse-height distribution.

Dynodes have been downsized to a width of 1 mm or 1 mm pitch, and the forming method was changed from press-working to etching. These are utilized in TO-8 type, square type, and flat-panel type photomultiplier tubes.

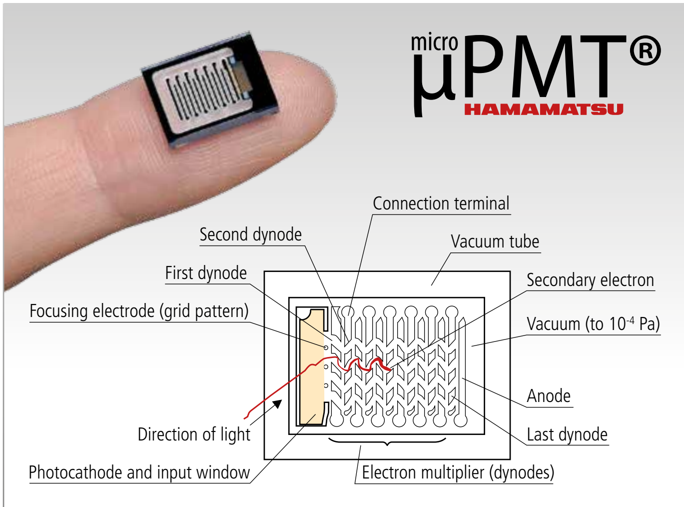
② Using this technology in micro PMT

The cross section structure of a micro PMT (photomultiplier tube) we successfully developed in September 2010 is basically based on the same concept. It incorporates the grid pattern placed immediately in front of the first dynode and the optimized position relation between the first and second dynodes. To obtain the same effect in preventing ions and light from feeding back to the photocathode, its vacuum envelope is made of glass plates with the inner side metalized with aluminum and a silicon substrate that blocks out light

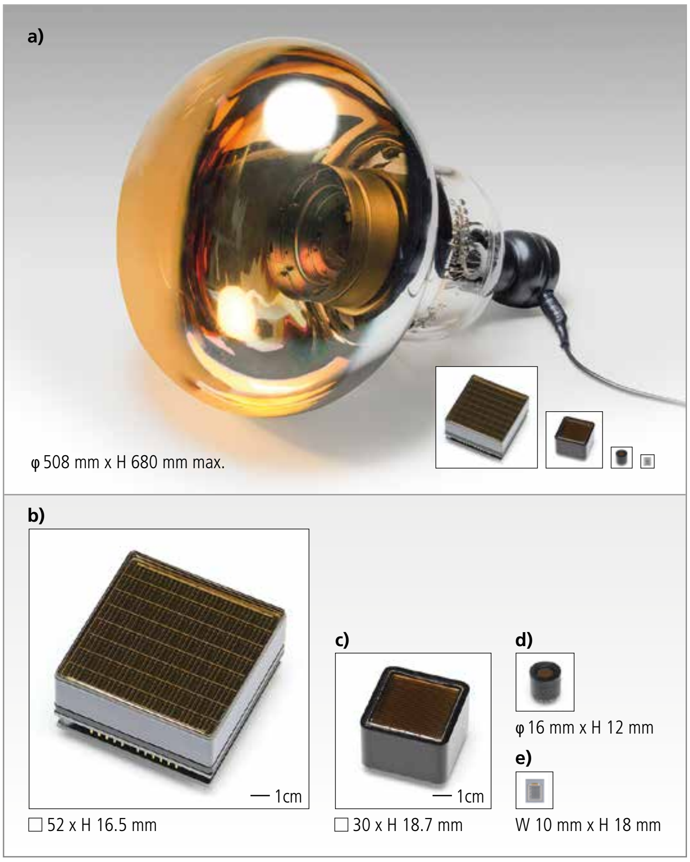
A 3-dimensional curved dynode structure was utilized in view of the vacuum envelope thickness to help minimize the gap between dynodes while providing electron multiplier pathways. Achieving this kind of 3-dimensional deep microstructure of silicon required advances in MEMS technology for deep microstructure RIE (reactive ion etching) which did not yet exist at the time of initial development of the micro PMT. This MEMS technology allowed forming the focusing electrode (grid pattern), all dynodes, anode, and the vacuum envelope at one time. These processes proved ideal for mass production of the micro PMT for the first time in the world in a manner similar to semiconductor manufacturing processes.

The photomultiplier tubes utilized the latest technologies available at that time and provided an innovative design and enhanced value. Those technologies were applied to various products ranging from the world's largest 20-inch photomultiplier tubes to the world's smallest micro PMT and from hereon we can anticipate even further dramatic advances.

Micro PMT (Photomultiplier tube)



Product size comparison (1/10th of actual dimensions)



a) 20-inch photomultiplier tube; b) flat panel type multianode photomultiplier tube; c) 1-inch square metal package photomultiplier tube; d) TO-8 metal package photomultiplier tube; e) micro PMT

Taking the lead by offering new choices in both high throughput and energy saving to the world's UV printing market.

Linear type UV-LED unit LIGHTNINGCURE® LC-L5G

Printers express and reproduce colors to an unbelievably realistic level to boost the basic product value. Among these, UV printers (printers using ultraviolet light to dry ink) are popular since they can print on almost any surface. The UV-LED light sources made by Hamamatsu Photonics are gaining a big name for themselves in the market of UV printers. Now, Hamamatsu offers the new linear type UV-LED unit "LIGHTNINGCURE LC-L5G." Compared to the conventional model LC-L5, the LC-L5G delivers drastically higher specs including 1.5 times the input power, 7 times the light output and half the cost, yet its size is one-third that of the LC-L5. We interviewed the development team members to find out how they succeeded in creating this new model which is drawing global attention at exhibitions.

Big expectations for UV-LED light sources from features found in conventional models

So what type of product is the LIGHTNINGCURE LC-L5G?

Suzuki: The LC-L5G is an LED light source that emits ultraviolet light. This product was designed to target the UV printing market. In addition to paper, UV printing works on all kinds of items including containers, cardboard boxes and boards. Moreover, the print quality is high and tact time (time for printing and drying) is short. Therefore the UV printing market is rapidly expanding all over the world.

Matsui: The technology to dry ink with ultraviolet light has been around for 60 years and UV printing itself has been steadily expanding for some 45 years. At the start of the 21st century, we saw an increasing demand in the UV printing market for shifting light sources from conventional metal halide lamps to energy-saving LED. At that time, UV-LED did not have enough output power and so failed to become widespread. About 5 to 6 years ago, UV-LED appeared having a light output equivalent to metal halide lamps. So now the use of UV-LED light sources has become practical.

Suzuki: When the conventional model LC-L5 was released 5 years ago, we foresaw it would be used in the market of UV curing for assembly of smartphones and tablet computers. Applying ultraviolet light to dry the adhesive is one application of UV curing. What we also focused on, at the same time, was the market of UV printers. There were plenty of enquiries about the conventional model, but these ended with the comment "it still does not have enough power." So we started designing and developing the LC-L5G in a bid to capture the printing market with a high-power model.

In other words, the ultimate mission for developing the LC-L5G was to make a high power model, right?

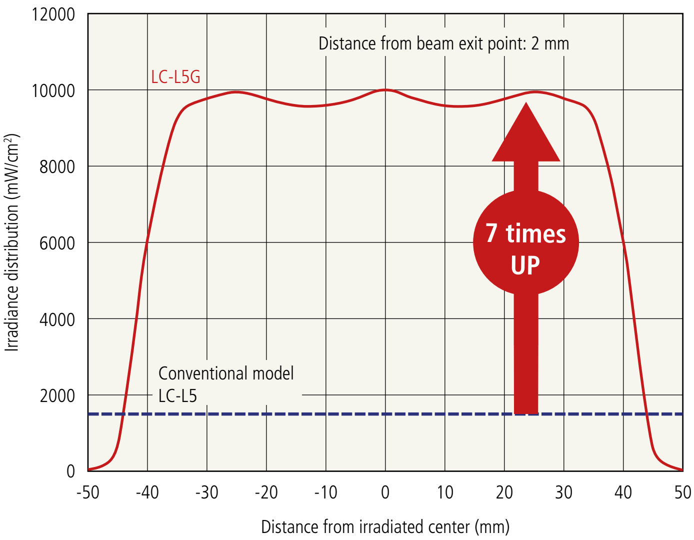
Suzuki: Yes, we knew through our conventional model that increased needs would arise in the printing market. We had to face the painful realization that our conventional model did not have enough power. In other words, we knew if we could increase light output we could acquire a larger market. We therefore poured all our efforts into accomplishing that goal.

Matsui: The LC-L5G achieves specs of 10 W/cm^2, which is the world's highest output level among air-cooled types. It is 1.2 times that of our competitor's products. Increasing the light output also boosts the printer throughput or, in other words, the production line speed.

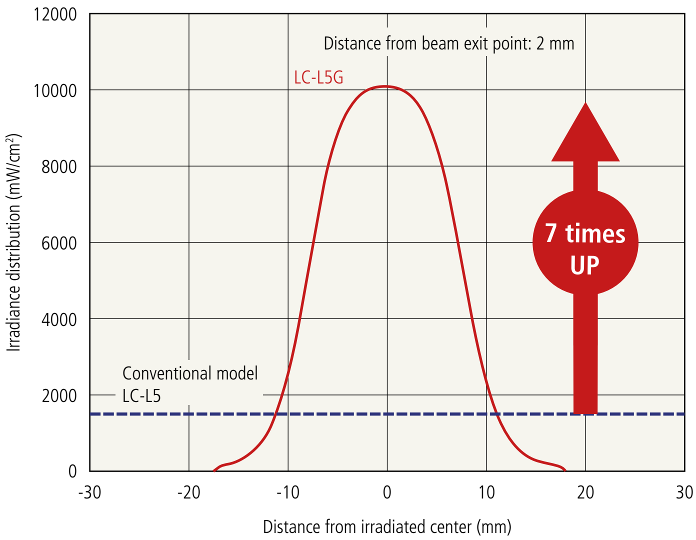
Suzuki: Currently, the metal halide lamp is the mainstream in light sources for UV printers, but it has a product service life of only 2,000 to 3,000 hours. However, by switching to UV-LED light sources, service life could be extended to 20,000 hours. The UV-LED may be more expensive in terms of initial investment, but the low running costs make it a true bargain in the long term.

Irradiance distribution

X direction



Y direction



The battle against heat, assessing options from every angle

What were the critical factors in designing a high power UV-LED?

Kashiwabara: The development requirements were extremely challenging … one third of the size, 1.5 times higher input power, 7 times higher light output and half the cost, yet a housing temperature about the same as a conventional model.

Murayama: The first time I heard these challenging requirements, they seemed so impossible that I couldn't believe my ears. Even on the conventional model we had a really hard time satisfying the heat dissipation requirements. Yet in spite of all that, we had to deal with increased heat emissions caused by the higher power output. Moreover, we were told this would not be water-cooled but must be air-cooled. To be honest, I thought accomplishing this was totally impossible.

But in spite of all this, you achieved your goals didn't you?

Matsui: At a point where about one year had passed since the start of LC-L5G development, we had reached the same level as our competitor's products and had mostly secured orders from customers satisfied with how our prototype functioned. However, at that point in time, we had only reached about 70 % of our target relating to heat dissipation design; a critical requirement. So we faced the extremely tough situation of how to reach a 100 % successful design in only about 3 months. In the end it was Mr. Murayama who succeeded.

Murayama: I knew I had to manage this heat dissipation issue, otherwise we couldn't complete development of this product. I studied the issue from all angles including selection of the housing material, heatsink size and fan, and the balance between the heatsink and the fan in an attempt to find a solution.

Matsui: Mr. Kashiwabara and I also worked on each responsible area to get rid of excess heat. All aspects were studied in each area and Mr. Murayama came through for us with the final breakthrough.

You also had to re-evaluate the electronic circuits I suppose?

Kashiwabara: Yes, we had to first reduce the circuit board size to one-third of the conventional model, which meant taking a new look at each and every circuit and closely examining what functions are needed and what functions are not. We basically had to scrape off any excess and if performance was low, select high performance parts and improve the circuit design in order to satisfy our target specifications. Of course we also had to meet demands to reduce costs which meant striking a balance between selecting electronic components and circuit design.

A team that never forgot "Don't say I can't. Say I'll try"

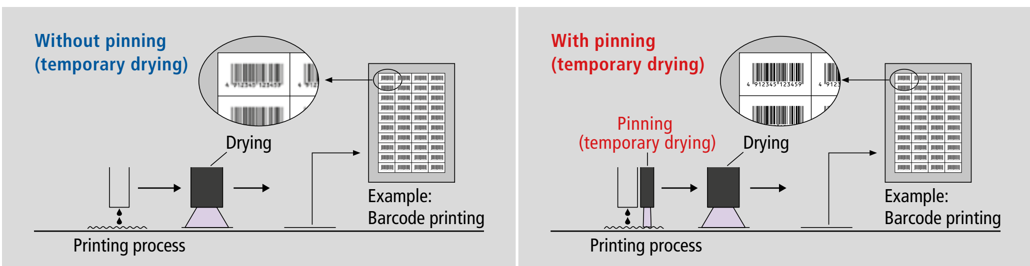
What was the reason for setting all of these tough design requirements?

Matsui: We first started out by fabricating what was basically an extension of our conventional model. However, a competitor of the same type UV-LED light sources already had a product capable of a light output of 8 W/cm^2. That was the point we realized that just making a better model than our old one only gave us a product with half the light output power of our competitors. That fact made us realize that "if another company can achieve such specs in that size, then we can do the same thing or even better. There is nothing that we cannot do if it's already on the market" and so we set all of these tough design conditions.

Suzuki: Those tough design conditions were also driven by customer demands and needs. Mr. Matsui set these design conditions to respond to what the market wanted to get.

And so you were finally able to overtake the competitor's product?

Matsui: I think the area where we overtook our competitors was due to the successful efforts of Mr. Murayama and Mr. Kashiwabara. At this point I can now say that if it came to the worse case scenario and Mr. Murayama's heat dissipation design didn't work, then I was starting to think of lowering our specifications to the same level as our competitor's product.



Pinning (temporary drying) ensures clear printing.

Murayama: I never heard about that… (laughter). Actually in the final part of development, we simply could not get the internal temperature to drop no matter what we did and so kept trying different experiments while sighing and hoping for better results. There were many times when I thought of going to Mr. Matsui and saying "I am really sorry, please make do with this." But something inside kept pushing hard to make me continue trying to make those target product specs a reality. After all kinds of experiments and design changes we finally succeeded, just barely meeting the deadline. I was really glad (laughter).

Suzuki: Our development team really showed great teamwork. I was involved in sales and even if I gave them a tough request such as "We need this" after listening to customer requests, the team would never say, "That's impossible" but would start thinking about what to do next. This team takes the words of Mr. Teruo Hiruma (Chairman of the Board of Hamamatsu Photonics) to heart "Don't say I can't. Say I'll try."

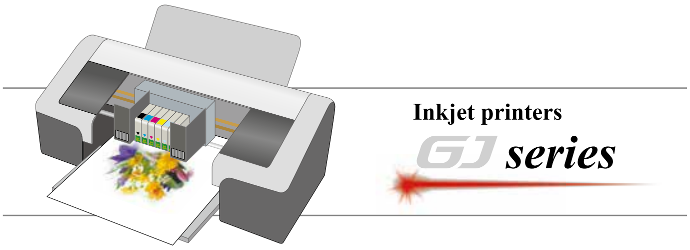
Mr. Matsui you really know how to put together a great team. What is your secret?

Matsui: That's not something I consciously think about, but I always welcome any ideas the members have to offer.

Murayama: He always listens to our ideas and if it looks possible he immediately says: "Let's try it." He is definitely someone easy to approach with new ideas and plans. When I was having a hard time with some problem, then Mr. Matsui and Mr. Kashiwabara would always come up with a lot of plans and suggestions which in turn caused many ideas to bubble up inside me.

Kashiwabara: If I proposed some type of approach to a problem with a circuit I was in charge of, then Mr. Matsui would say: "You might also try this other approach." These types of exchanges helped create new ideas and after agreeing on them we were able to start making progress.

PLEASE READ ALSO PRODUCT INFORMATION ON PAGE 24.



Making our photonics technology major in the UV printing market

What do you see as the likely new trends in the future?

Suzuki: During 2016 and beyond we will be offering various types of UV-LED to support a variety of printers including inkjet, screen, flexographic, pre-drying, etc. I recently visited a printer exhibition in Europe where I found that the UV printing market is demanding light output power higher than current product specifications. That will be the next future issue to deal with.

Murayama: That means I will have to start looking for a more efficient method to reduce heat.

Kashiwabara: I will be studying how to increase the input power to the circuitry. But driving circuits with high electrical power generates a great deal of heat. Figuring out how to put heat dissipation technology to work to eliminate heat in a limited space will be a development issue where our entire team will have to work together to make progress.

Matsui: I hope our UV-LED light sources will prove a valuable asset in markets involved with printing applications. I think it would be great if technology utilizing light and optics could be expanded even further into the printing market.

Suzuki: Applying not only UV-LED light sources but also excimer lamp light sources to printing applications is being studied. Hamamatsu Photonics is a major player in the medical treatment and chemical analytical markets, but is still not well known in the printing market. We will be working hard to also gain a name for "Hamamatsu" in the printing market.

Members (from the left)

Hiroya Kashiwabara, *Electron Tube Division, Manuf. #4 (in charge of electrical circuitry)*

Kyoichi Murayama, *Electron Tube Division, Manuf. #4 (in charge of housing & heat dissipation design)*

Ryotaro Matsui, *Electron Tube Division, Manuf. #4 (coordinator of development project, in charge of LED)*

Akimasa Suzuki, *Electron Tube Division, Business Promotion 2nd Group (in charge of sales)*

Using super-resolution nanorulers to study the capabilities of EM-CCD and sCMOS cameras beyond the diffraction limit

Light microscopes enabling super-resolution imaging suffer from a standardized quantification method. We demonstrate the quantification of a super-resolution microscope by using standardized DNA origami samples with the help of two leading camera technologies (EM-CCD and sCMOS).

1. Overview

Recently, the Nobel Prize in chemistry was awarded to Stephan Hell, Eric Betzig and William E. Moerner for their groundbreaking improvements in optical and single molecule microscopy. Their fundamental work and innovative approaches made it possible to image structures smaller than the diffraction barrier of light (~200 nm), a limit which was first introduced by Ernst Abbe in 1873. The development of novel types of microscopes, so called 'super-resolution' microscopes, enabled the visualization of biological processes on a molecular level and improved the insight in diverse fields of biomedicine such as neuroscience, morphogenesis or drug delivery, to name a few. Researchers developed a large number of methods to overcome the diffraction barrier based on spatiotemporal fluorescent switching.

In this paper, we performed a standard single molecule switching nanoscopy (SMSN) technique to demonstrate how two camera technologies (EM-CCD and sCMOS) can resolve the world's first standardized nano samples. The utilization of nanostructured standards from GATTAquant GmbH offered the opportunity to test the super-resolution capability of Hamamatsu´s leading camera technologies in a quantitative and reproducible way.

2. Introduction

In nature nearly all biomolecules are smaller than 200 nm. As a consequence, the finest structures of fluorescently labeled cells and their molecular components are hidden under the intensity peak from a single point source of light (point-spread function – PSF), which is emitted by a nanoscaled fluorophore. To overcome this barrier, super-resolution microscopy makes use of the changing states of fluorescence markers and measures the shape of the blinking PSF[1]. In general there are two main techniques to achieve a bright ON or dark OFF state of fluorophores, either by deterministic photoswitching in space or by stochastically switching single molecule fluorescence ON and OFF in space and time. Prominent methods of the first technique involves ground state depletion (GSD) microscopy[2], reversible saturable optical fluorescence transition (RESOLFT) microscopy[3], linear or saturated structured illumination microscopy[4, 5] ((S)SIM) or stimulated emission depletion (STED) microscopy[6]. In the field of stochastic imaging (direct) stochastic optical reconstruction microscopy[7, 8] ((d)STORM), (fluorescence) photo-activation localization microscopy[9, 10] ((f)PALM), or (DNA-based) point accumulation for imaging in nanoscale topography[11] ((DNA-)PAINT) are known to be commonly used.

Nevertheless, whichever technique is applied, samples with standardized dimensions are missing. Recently founded GATTAquant GmbH utilizes state-of-the-art innovations in the field of DNA nanotechnology to fabricate probes for fast, easy and precise quantification of super-resolution systems[12, 13]. The samples allow the quantification of the resolution of the microscope with a precision of a few nanometers. This is possible by using special nanoconstructs, so called 'DNA origami structures'[14-16], as a breadboard for placing single dye molecules in an exactly defined pattern. This technique allows the placement of fluorophores in preassigned distances, subsequently serving as a ruler on the nanoscale. To study the capabilities of different cameras we focused on nanorulers using DNA-PAINT as SMSN technique (GATTA-PAINT 80R nanoruler). DNA-PAINT is based on the transient binding of fluorophore-labeled "imager" strands to complementary target positions on the nanoruler, enabling a stochastic blinking and subsequently allowing for the reconstruction of a super-resolved image[17].

Besides the blinking technique itself and the optical instrument, which is necessary to perform super-resolution imaging, the camera is a key component. The sensor records the PSF, which is used to reconstruct the super-resolved image. Currently there are two leading camera technologies on the market, which are suitable for super-resolution imaging. In general, both offer a very low readout noise characteristic. The widespread electron multiplying charge coupled device (EM-CCD) cameras multiply the number of electrons on-chip before digitalization. New scientific complementary metal oxide semiconductor (sCMOS) cameras show comparable low-light sensitivities. In general, they are governed by an order of magnitude higher read noise (~1 e^-) but do not suffer from electron multiplication noise compared to EM-CCDs.

The goal of this white paper is to envision the capability of Hamamatsu's cameras for super-resolution imaging using both EM-CCD and sCMOS technologies with the help of GATTAquant's standardized nanorulers.

3. Imaging technologies

Currently, there are two leading technologies in the field of ultra-low light camera detectors. Super-resolution imaging is clearly considered for ultra-low light applications since typical light levels are less than 1000 photons per pixel per frame. On the one hand there is the Electron Multiplying Charge Coupled Device (EM-CCD) sensor which multiplies the photoelectrons in an electron multiplying register on the chip and on the other hand the scientific grade Complementary Metal Oxide Semiconductor (sCMOS) sensor which amplifies the photoelectrons on the pixel directly. Typically, these different signal processes introduce different readout noise levels and characteristics[20, 21]. The electron multiplication in EM-CCD enables the detection of weak light and lowers the readout noise to less than 1e$^-$ (rms) but introduces additional noise (excess noise) which effectively lowers the superior quantum efficiency of more than 90 % by a factor of 2. In contrast, sCMOS cameras do not suffer from excess noise but show a higher readout noise of 1.4 e$^-$ (rms). With the help of the following equation the signal-to-noise ratio can be calculated theoretically.

In the equation, QE is the quantum efficiency which is the ratio of incident photons to converted electrons. For the sCMOS camera the peak quantum efficiency is 72 % (at 560 nm) and for the EM-CCD 92 % (at 560 nm). Further, S is the digital signal value in analogue digital units (ADU). I_b is the signal intensity of the background in the experiments. N_r is the readout noise and is a statistical expression of the variability within the electronics that convert the charge of the photoelectrons in each pixel to a digital number. EM gain occurs in a voltage dependent, stepwise manner and the total amount is a combination of the voltage applied and number of steps in the EM register. EM gain has a statistical distribution and an associated variance, which is accounted for by Fn. At typical EM-CCD gains up to 1200, $F_n = \approx 1.4$. Since CCD and CMOS do not have EM gain, $F_n = 1$ in these cameras. Please note that in this calculation the dark current is neglected because exposure times in localization experiments are typically less than 1 s.

In Figure 1, the signal-to-noise ratio in absolute values versus input signal photons in number of photons per pixel is plotted. Values are taken from the data sheets of the cameras. The blue line corresponds to the sCMOS camera and the green line to the EM-CCD camera. Additionally the effect of excess noise in EM-CCD cameras is plotted and expressed by the purple line. As sCMOS technology has a six fold smaller pixel area, the corrected plot for sCMOS is also shown and denoted as the red line. The graph suggests small advantages for sCMOS technology in terms of sensitivity of more than 10 photons per individual pixel (intersection of blue and green line). If excess noise is accounted for with the EM-CCD, this intersection shifts to 4 photons per individual pixel. However, the corrected pixel sizes for the sCMOS camera reveals a 30 % better SNR.

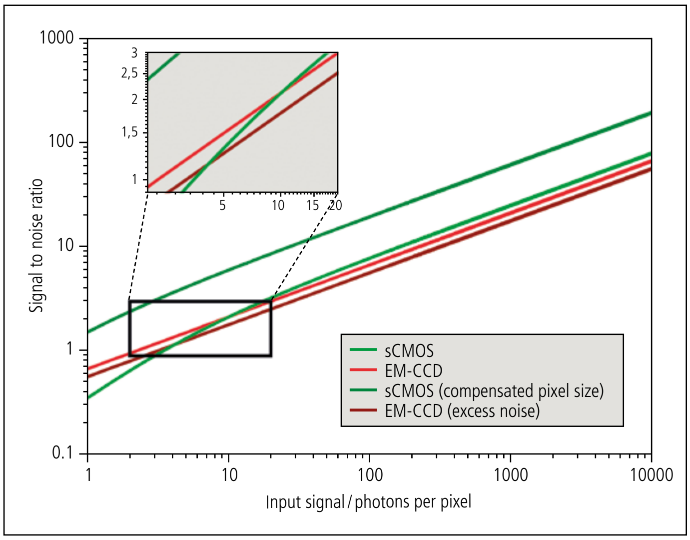


Figure 1: Theoretical signal-to-noise ratios for EM-CCD (green) and sCMOS (blue) in dependency of input photons per individual pixel at 688 nm. The purple line is the excess noise corrected SNR-plot for the EM-CCD and the red line compensates the different pixel sizes of the two sensors.

In some super resolution applications the acquisition speed may be another interesting sensor parameter that makes your application demanding. The EM-CCD camera allows 70 fps at full resolution whereas the rolling shutter in the sCMOS camera allows for an operation at 100 fps at full resolution.

4. Materials and methods

Super-resolution standards (GATTA-PAINT 80R nanoruler) were provided as ready-to-use slides from GATTAquant GmbH, Braunschweig, Germany.

High sensitivity cameras (ImagEM X2 and ORCA-Flash4.0 V2) were provided by Hamamatsu Photonics Deutschland GmbH, Herrsching, Germany.

Super-resolution imaging was performed on a custom-built total internal reflection fluorescence (TIRF) microscope, based on an inverted microscope body (IX71, Olympus). For excitation, a 150 mW, 644 nm diode laser was used (iBeam smart, Toptica Photonics) which was spectrally filtered using a clean-up filter (Brightline HC 650/13, Semrock) and coupled into the microscope with a beamsplitter (zt 647 rdc, Chroma). The laser beam was focused to the backfocal plane of an oil-immersion objective (100x, NA = 1.4, UPlanSApo, Olympus) and aligned for TIRF illumination. In addition, a 1.6x optical magnification was applied resulting in an effective pixel size of 100 nm (EM-CCD) or 40.6 nm (sCMOS). The fluorescence light was spectrally filtered by an emission filter (ET 700/75, Chroma). For imaging, an electron multiplying charge coupled device (EM-CCD, ImagEM X2, Hamamatsu) or a scientific complementary metal oxide semiconductor (sCMOS, ORCA-Flash4.0, Hamamatsu) camera was used. To minimize setup and sample drift, the microscope was mounted on an actively stabilized optical table (TS-300, JRS Scientific Instruments). Additionally, the objective was mounted via a nosepiece (IX2-NPS, Olympus).

Typical acquisition parameters were: laser power: ~9 kW/cm^2, integration time: 30 ms, number of frames: 10,000, EM gain (for EM-CCD camera): 150. Acquisition was controlled by open source microscopy software Micro-Manager, followed by analysis using custom-built spot finding and 2D-Gaussian fitting algorithms based on MATLAB and LabVIEW. Reconstructed images with resolved nanorulers were finally analyzed using the GATTAnalysis software from GATTAquant GmbH.

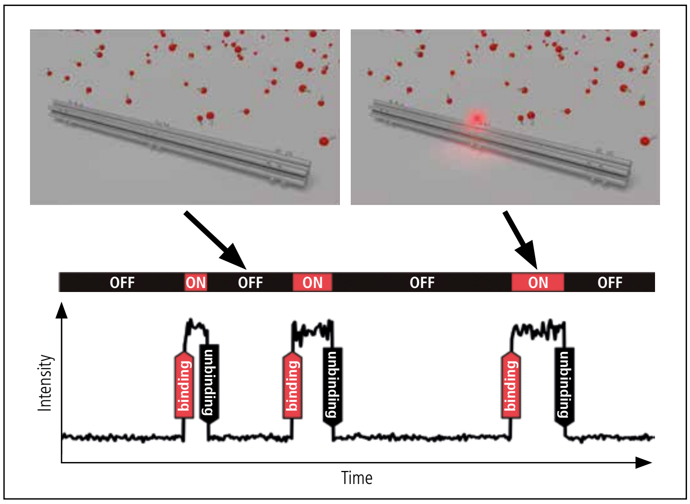


Figure 2: Illustration of the DNA-PAINT imaging technique: The transient binding and unbinding of fluorescently labeled oligonucleotides to specifically designed binding sites, mimics a signal of blinking dye molecules which can be processed in the same way as standard localization based SR microscopy.

5. Results and discussion

The GATTA-PAINT 80R nanorulers are straight rods based on DNA origami structures, featuring three marks for DNA-PAINT imaging designed with a distance of 80 nm between two adjacent marks (and consequently 160 nm between the two exterior marks). The fluorescence signal is based on the transient binding of ATTO 655 labeled imager oligonucleotides to the complementary target marks on the

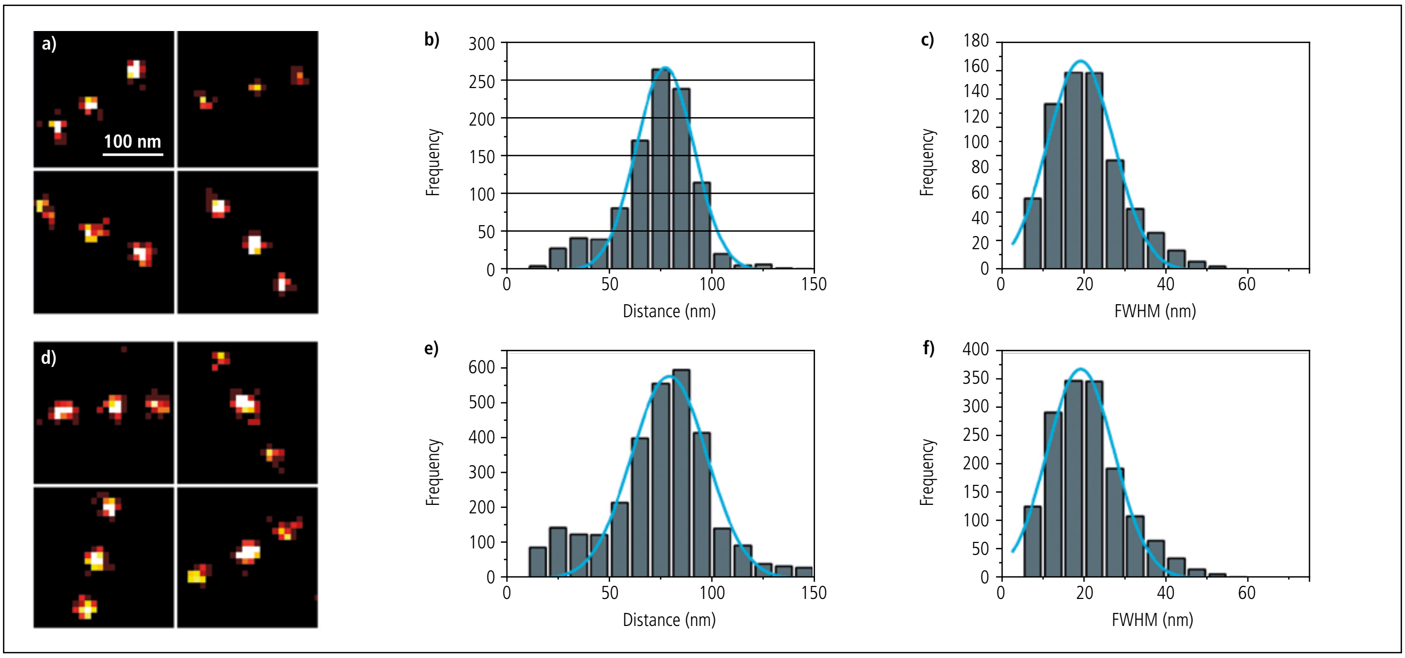


Figure 3: a) DNA-PAINT images of GATTA-PAINT 80R nanorulers acquired with an EM-CCD camera. b) Gained distance histogram showing an average distance of (77 ± 14) nm. c) Gained histogram of the individual mark FWHMs showing an average FWHM of (25 ± 6) nm. d) DNA-PAINT images of GATTA-PAINT 80R nanorulers acquired with an sCMOS camera. e) Gained distance histogram showing an average distance of (79 ± 18) nm. f) Gained histogram of the individual mark FWHMs showing an average FWHM of (19 ± 8) nm.

nanoruler (Figure 2). The data presented originates from the identical probe, whereas the cameras were exchanged during this study.

For both camera types – the EM-CCD and the sCMOS – hundreds of nanorulers could be resolved, confirming the qualitative capability for super-resolution imaging and subsequent image reconstruction. The reconstructed image, given as a 2D heat map of the single events, clearly shows the three in-line marks of the nanoruler (Figure 3a and d).

Using the GATTAnalysis software both the distances between adjacent marks and the full width at half maximum (FWHM) of every individual mark is determined for each ruler, respectively. The results are binned in a histogram and fitted accordingly with a Gaussian. The EM-CCD camera shows an average distance of (77 ± 14) nm for the GATTA-PAINT 80R nanoruler (Figure 3b) with a FWHM of (25 ± 6) nm (Figure 3c). Using the same acquisition parameters for the sCMOS camera, the distance values of (79 ± 18) nm tend to be very similar in comparison to the EM-CCD camera (Figure 3e), nevertheless the FWHM is clearly shifted to (19 ± 8) nm, resulting in an improved FWHM by 24 % (Figure 3f).

In the following the intensity signals of the blinking events are identified in detail for both the EM-CCD and sCMOS. Therefore, 10 intensity levels from the blinking spots from 10 different frames are measured. The EM-CCD showed average intensity values of (29,098 ± 8,590) ADU and the sCMOS (768 ± 266) ADU. Both camera sensors allow 16 bit ADU values so that the EM-CCD is saturated by 44 % and the sCMOS to only 1.2 % on average. However to calculate the signal-to-noise ratio the background signal also has to be taken into account. To identify the average background signals the mean value of a square is measured (see Figure 4). The EM-CCD has background intensities of (15,224 ± 564) ADU and the sCMOS (282 ± 21) ADU. Now these values can be used to calculate the signal-to-noise ratios as previously explained (see equation 1). The EM-CCD shows a SNR of 93 per pixel and the sCMOS 20 per pixel. Considering the six times smaller pixel area ($256\ \mu m^2$ / $42.25\ \mu m^2$ = 6) of the sCMOS this value increases to 120. In other words the sCMOS sensor has an improved SNR of 30 %. This fact validates the theoretical SNR consideration discussed before (see Imaging Technologies).

Nevertheless the intensities are highly sufficient for threshold-based spot finding and subsequent 2D Gaussian fitting. The calculated distance values of the reconstructed nanorulers only slightly deviate for each camera type. Further they strongly agree with the designed distance of 80 nm within the given standard error. The FWHM for the EM-CCD is found to be around 25 nm, a value comparable to previous DNA-PAINT measurements[17-19]. Nevertheless, our finding that the FWHM for the sCMOS is around 19 nm opens the potential use of these camera types for single molecule measurements.

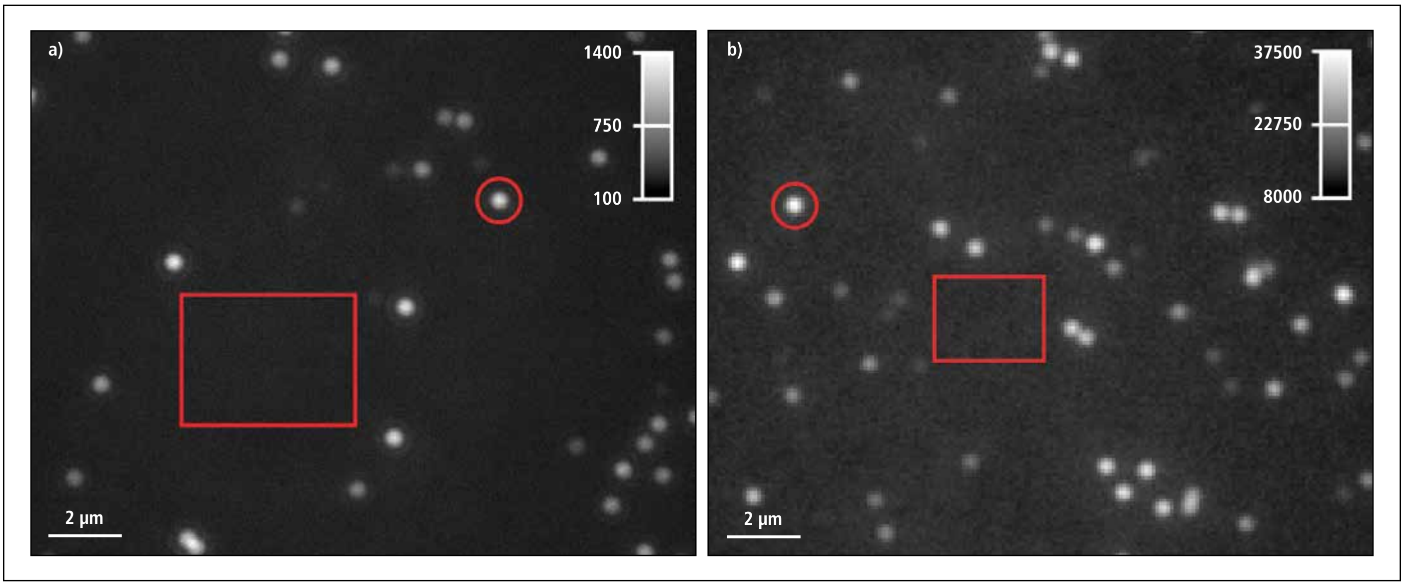


Figure 4: a) sCMOS raw image (480 x 360 pxls) b) EM-CCD raw image (192 x 144 pxls). The images are 8bit LUT corrected. A red square identifies the area where the background intensity was identified in the SNR calculation. The red circle measures a PSF of a fluorophore. The color scales indicate the intensity values in ADU.

6. Conclusions

The utilization of GATTAquant´s standardized nanostructures for super-resolution microscopy offers a variety of advantages compared to previous test samples like microtubules or fluorescent beads. It is the first time that a large amount of identical patterns, with defined distances, is available and these nanorulers allow for the parallel analysis and statistical validation of the resolution of the set-up. In addition, their fluorescent properties are – due to the selected type and number of dyes – comparable to real samples, for instance mimicking classically stained cell samples in a more comparable way to setup parameters and settings.

Now, the utilization of these standard probes enables the verification of the performance of different camera types under uniform (or stable) conditions. The statistical data evaluation allows a direct comparison of Hamamatsu´s EM-CCD and sCMOS cameras and confirms their benefit for super-resolution imaging.

The SNR measurement showed small advantages for sCMOS technology. Recently, Hamamatsu launched a new sCMOS camera with 10 % increase of quantum efficiency over the visible spectra. This makes sCMOS technology even more suitable for super-resolution imaging.

Key words
DNA-PAINT, Standardized Super Resolution, Ultra Low Light Camera, Nanoruler, sCMOS, EM-CCD

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NEW

MPPC S13360 Series

Low crosstalk MPPC® for precision measurement

The S13360 series are MPPCs for precision measurement. They inherit the superb low afterpulse characteristics of previous products and further provide lower crosstalk and lower dark count. Various types with different photosensitive areas and pixel pitches are available.

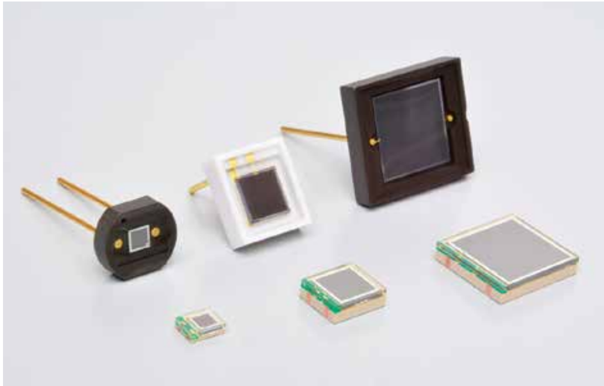
Features

- Reduced crosstalk and dark count (compared to previous products)
- Excellent photon-counting capability (excellent detection efficiency versus number of incident photons)
- MPPC array also available (S13361 series)

Applications

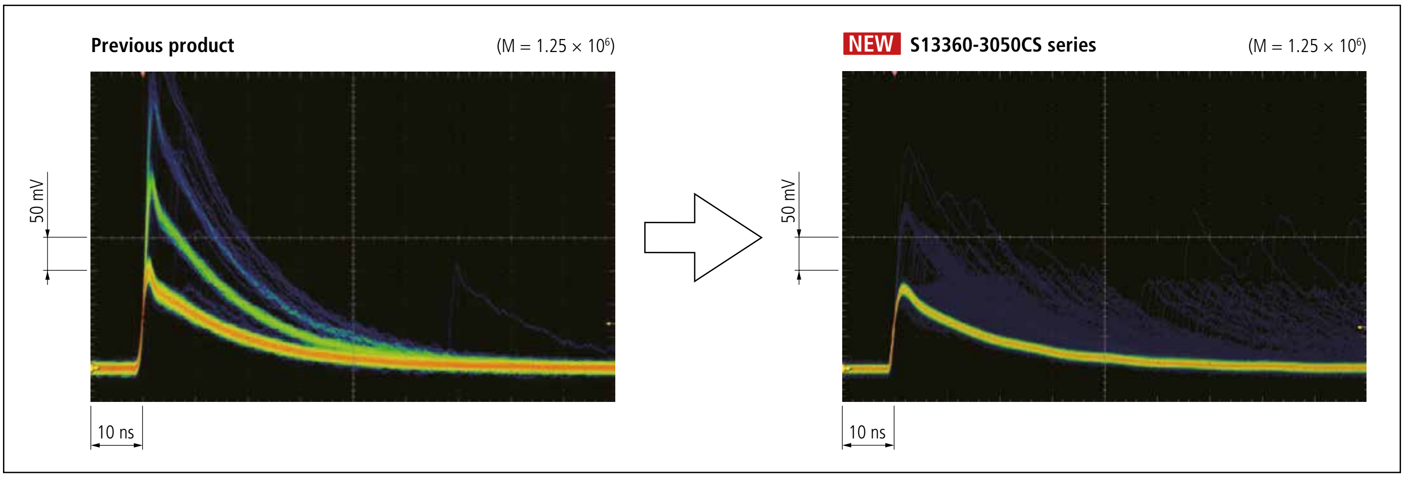
- Fluorescence measurement
- Laser microscope
- Flow cytometry
- DNA sequencer

For details on product specifications, visit our website.



S13360 series

Pulse waveform comparison (typical example)



MPPC module
C13365 Series, C13366 Series

NEW

Low-light-level measurement module with built-in new MPPC

The C13365/C13366 series are modules capable of low-light-level detection with a new built-in MPPC for precision measurement. These modules consist of an MPPC, an amplifier, a high-voltage power supply circuit, and a temperature compensation circuit. The modules operate by simply connecting them to an external power supply (±5 V). Digital output and analog output types are available.

C13365 series, C13366 series

Features

- New MPPC for precision measurement built-in
- High sensitivity in the short wavelength range
- Low noise equivalent power
- Built-in temperature compensation circuit
- Compact and lightweight

Applications

- Low-light-level measurement

Specifications

Parameter	C13365		C13366				Unit
	-1350SA	-3050SA	-1350GA	-3050GA	-1350GD	-3050GD	
Output	Analog		Analog		Digital		-
Cooling	Non-cooled		Cooled		Cooled		-
Photosensitive area	1.3 x 1.3	3.0 x 3.0	1.3 x 1.3	3.0 x 3.0	1.3 x 1.3	3.0 x 3.0	mm
Number of pixels	667	3,600	667	3,600	667	3,600	-
Pixel pitch	50		50		50		μm
Photoelectric sensitivity	1.0×10^9		1.0×10^9		-		V/W
Photon detection efficiency	-		-		40		%
Noise equivalent power*1	0.5	1.2	0.1	0.15	-		$fW/Hz^{1/2}$
Dark count*2	-		-		2.5	12	kcps

*1 Dark state
*2 Threshold: 0.5 p.e.

NEW

MPPC
S13190 Series, S13615 Series

MPPCs in a chip size package miniaturized through the adoption of TSV*1 structure

The S13190/S13615 series are MPPCs for precision measurement miniaturized by the use of TSV and CSP*2 technologies. The adoption of a TSV structure made it possible to eliminate wiring on the photosensitive area side, resulting in a compact structure with little dead space compared with previous products. The four-side buttable structure allows multiple devices to be arranged side by side to fabricate large-area devices. The S13190 series offers wide dynamic range, whereas the S13615 series feature low crosstalk. MPPC arrays with higher resolution than previous products are also available.

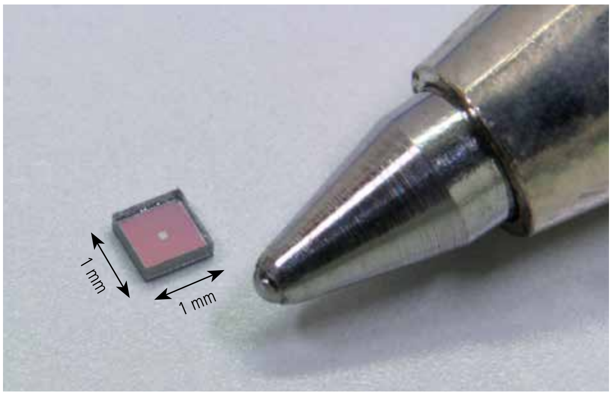
Features

- Compact chip size package with little dead space
- Low cost
- Wide dynamic range
- Low afterpulses
- MPPC arrays also available

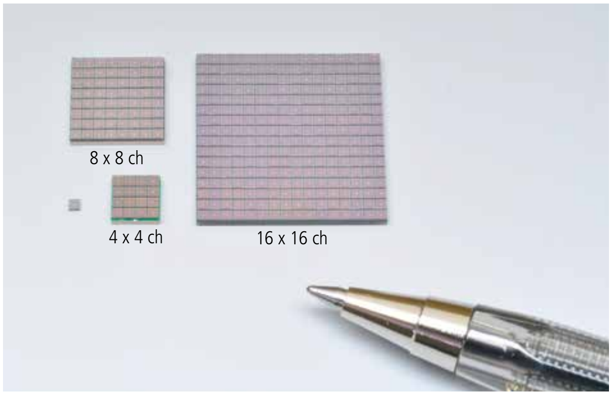
Applications

- Distance measurement
- Nuclear medicine
- High energy physics experiments

*1 Through-silicon via *2 Chip size package

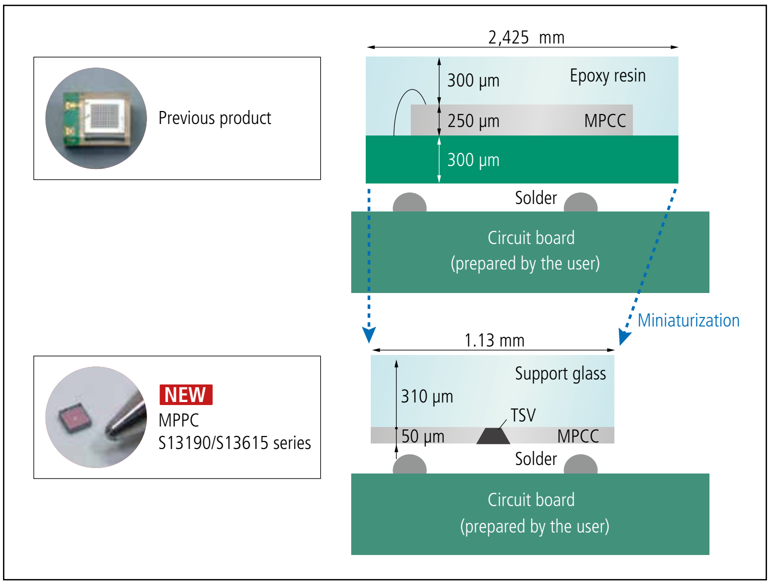


S13190 series, S13615 series



Examples of MPPC arrays

Structure comparison with a previous product



Micro-Spectrometer TF Series C13555MA, C13053MA, C13054MA

NEW

High performance mini-spectrometers in an ultra-slim package

The TF series are high performance mini-spectrometers in a 12 mm deep, ultra-slim package. Utilising a high-sensitivity CMOS linear image sensor results in a sensitivity equivalent to that of a CCD, with low power consumption. A trigger function for short integration times, enables spectroscopic measurement of pulse emissions. The C13054MA is a high resolution mini-spectrometer suitable for Raman spectroscopy.

C13054MA

Features

- Compact, ultra-thin package
- High-sensitivity CMOS linear image sensor
- Trigger compatible (software trigger, external trigger)
- USB bus powered (no external power supply necessary)

Applications

C13555MA

- Visible light source inspection
- Color measurement

C13053MA

- Sugar content and acidity measurement of foods
- Plastic screening
- Film thickness gauge

C13054MA

- Raman spectroscopy

Specifications

Type	Type no.	Photo	Spectral response range (nm) 200 400 600 800 1000 1200 1400	Spectral resolution max. (mm)	Integration time (μs)	Trigger function	Internal image sensor	
							Type	Pixels
HIGH SENSITIVITY TF series	C13555MA		340 to 830	3	11 to 100,000	Yes	High-sensitivity CMOS linear image sensor	512
	C13053MA		500 to 1,100	3.5				
HIGH RESOLUTION TF series for Raman spectroscopy	C13054MA		790 to 920	0.7				

NEW

Photosensor with front-end IC S13645-01CR

16 channel distance measurement APD array for direct TOF*1

The S13645-01CR is a device designed for direct TOF measurement. It integrates Hamamatsu's 16 ch Si APD array and TIA*2. It has a built-in DC feedback circuit for reducing the effects of background light. It also provides excellent noise and frequency characteristics.

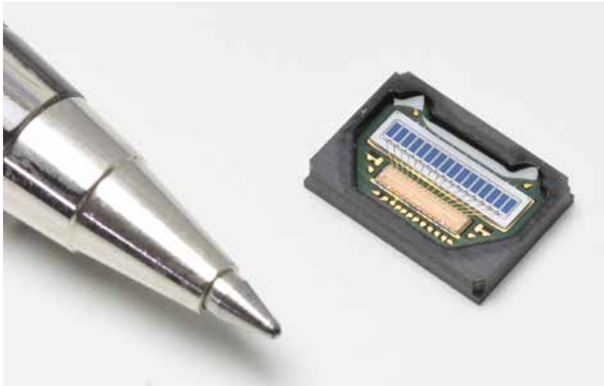
Features

- Integration of 16 ch Si APDs and TIA
- High-speed response: 200 MHz
- Background light elimination function
- Switchable gain amp (x1 or x20)
- No waveform distortion with excessive incident light

Applications

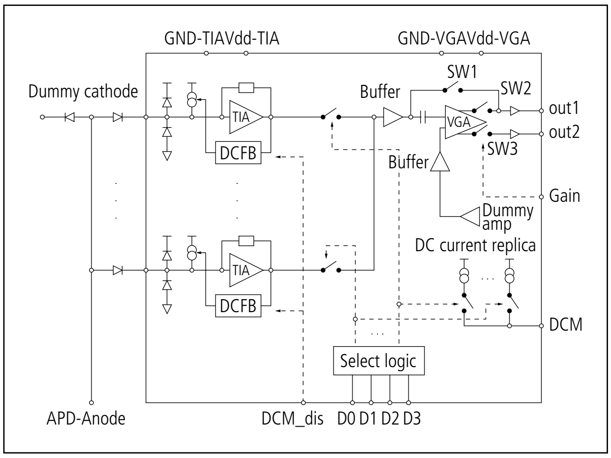
- Distance measurement
- Object detection

*1 Time-of-Flight *2 Trans-impedance amplifier



S13645-01CR

Block diagram



Specifications

Parameter		Specification	Unit
Photosensitive area/ch (H x V)		0.4 x 1.0	mm
Peak sensitivity wavelength		840	nm
Feedback resistance		2.5	kΩ
Cutoff frequency		200	MHz
Noise equivalent characteristics		160	$fW/Hz^{1/2}$*3
Gain	High gain	1,000	kV/W*3
	Low gain	50	

*3 λ = 840 nm, M = 50 at 10 MHz.

Photo IC for Rangefinder S13021-01CT

NEW

1 channel distance measurement photo IC for indirect TOF*1

The S13021-01CT is a distance measurement device using the indirect TOF method. It integrates Hamamatsu's CMOS sensor and signal processing circuit. The sensor outputs signals proportional to the time for the pulse-modulated light reflect by the target object and return. The output value can be used to calculate the distance to the target object. The S13021-01CT runs on low voltage (3.3 V) and supports I²C and SPI interfaces.

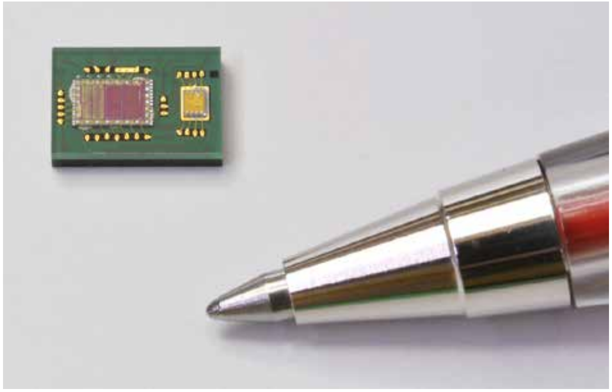
Features

- Low voltage operation (3.3 V)
- I²C interface/SPI ready
- Built-in 16-bit A/D converter

Applications

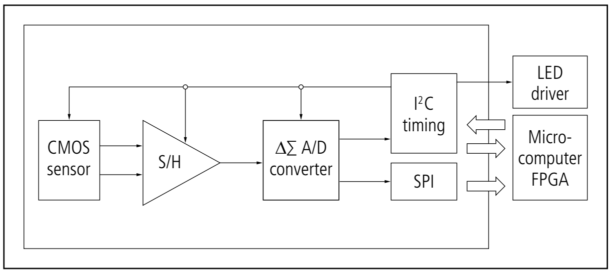
- Distance measurement
- Object detection

*1 Time-of-Flight



S13021-01CT

Block diagram



Specifications

Parameter		Specification	Unit
Photosensitive area		0.4 x 0.4	mm
Peak sensitivity wavelength		800	μm
Current consumption		12	mA
Output voltage	Dark state*2	1.4	V
	When saturated	0.65	

V_{DD} = 3.3 V
*2 Output value immediately after reset

NEW

CMOS Linear Image Sensors S11639-01, S13496

High sensitivity, employs vertically long pixels

The S11639-01 and S13496 are high sensitivity CMOS linear image sensors employing a photosensitive area consisting of vertically long pixels (pixel height: 200 μm). High sensitivity and high resistance have been achieved, even in the ultraviolet region. These sensors operate on a single 5 V power supply making them suitable for low cost spectrometers.

Differences from previous products

Readout noise and dark current were reduced to approximately half those of the previous product. Moreover, variations in sensitivity in the ultraviolet region (200 to 300 nm) have been suppressed.

Features

- High sensitivity in the UV to near IR region
- Simultaneous integration of all pixels
- Variable integration time function (electronic shutter function)
- Single 5 V power supply operation

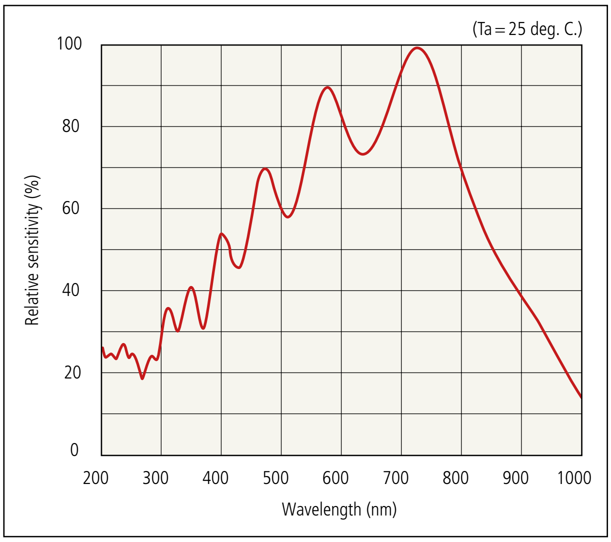
Applications

- Spectroscopy
- Position detection
- Image scanning
- Encoders

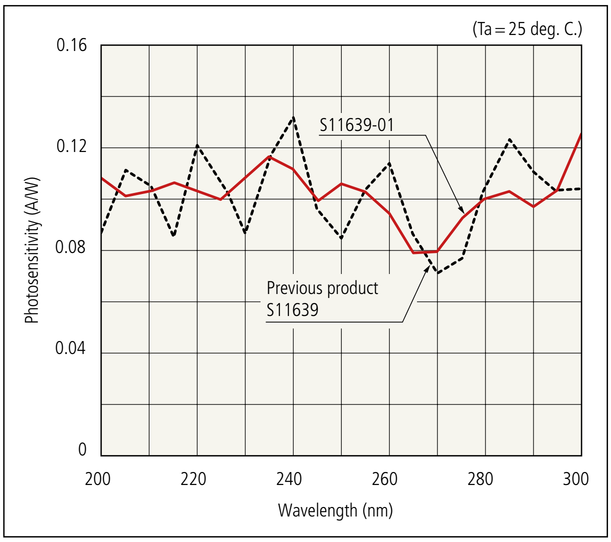
Specifications

Parameter	S 11639-01	S13496	Unit
Number of effective pixels	2,048	4,096	pixels
Pixel size (H x V)	14 x 200	7 x 200	μm
Effective photosensitive area length	28.672		mm
Spectral response range	200 to 1,000		nm
Photosensitivity	1,300	650	V/(lx·s)
Readout noise	16		e^- rms
Video data rate (max.)	10		MHz

Spectral response (typical example)



Spectral response in the ultraviolet region (S11639-01, typical example)



Linear Type UV-LED Unit LIGHTNINGCURE LC-L5G L12990-2303

NEW

High output 10,000 mW/cm² UV-LED replacing metal-halide lamps

The L12990-2303 delivers high power while still maintaining the features of our current product original LC-L5 including compact size, light weight and air cooling. These features have traditionally been a challenge for UV-LED light sources until now.

The L12990-2303 offers a light intensity of 10,000 mW/cm² which is about 7 times higher than our original product (LC-L5), making it suitable for high throughput applications that requires a high UV output.

Features

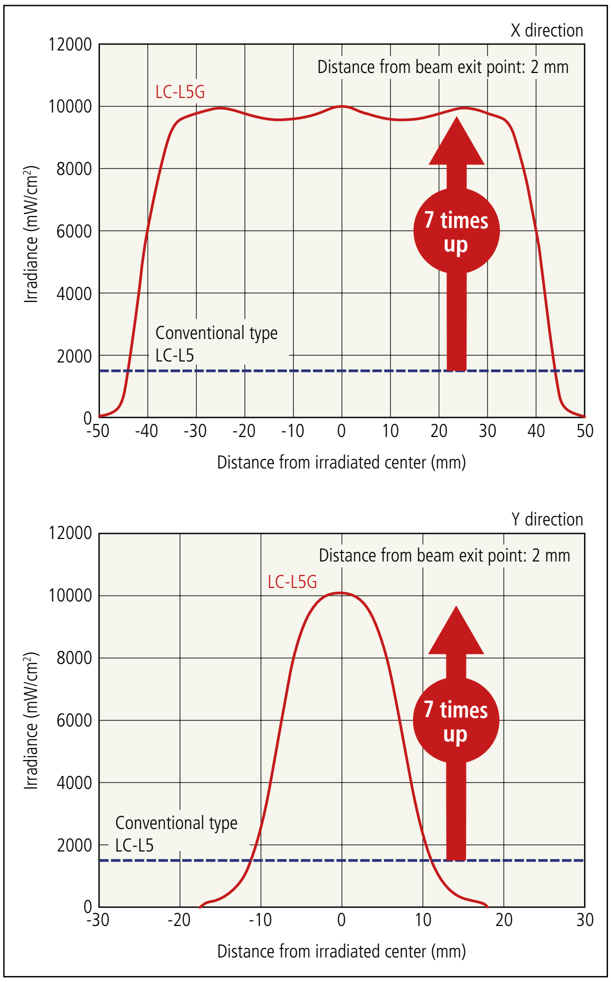
- High output 10,000 mW/cm²
- Air cooling by fan
  - No exhaust duct installation and no chiller equipment required
- Compact and light weight

Applications

- UV ink drying
  - UV inkjet printer
  - UV seal & label printing
  - UV offset printing
- UV coating agent drying
  - Printed circuit board protective film
  - IC card & IC tag coating
  - Blu-ray & DVD media coating
  - Furniture & building material (wall, floor, etc.)/woodworking applications
- Fluorescence excitation/scratch & flaw inspection lighting

L12990-2303

Irradiance distribution



Specifications

Parameter	Specification	Unit
Irradiation area*1	12 x 75	mm
Maximum UV irradiance intensity*2	10,000	mW/cm²
Peak wavelength	385±5	nm
Input voltage (DC)	48	V
Power consumption (max.)	600	W
LED design life*3	20,000	h

*1 Area subject to at least 80 % irradiance at distance of 2 mm.
*2 Within irradiation area, at 2 mm of irradiation distance.
*3 Average time until irradiance reaches 70 % of initial value.

PLEASE READ ALSO R & D INTERVIEW ON PAGE 8.

NEW

Deuterium Lamp for Photoionization L13301

Higher output than PID lamps
Compact deuterium lamp for photoionization

In mass spectrometry and gas chromatography, photoionization or ionization by light is the focus of attention as a soft ionization technique that does not cause excessive damage to measurement samples. Up until now, PID (photo-ionization detector) lamps and lasers have been used as the light sources for photoionization. However, PID lamps have insufficient output and lasers require designing a large, complicated system that is not easy to handle. The L13301 deuterium lamp optimized for soft photoionization will solve those problems.

L13301

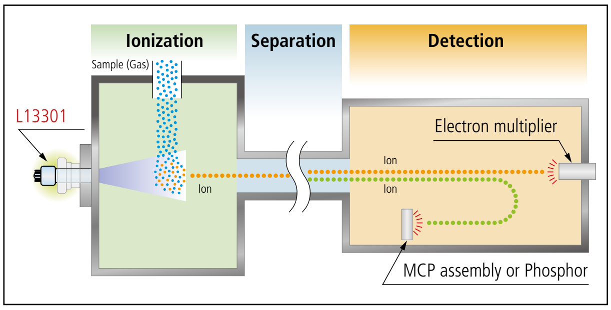
Features

- Capable of soft ionization
- High energy: 10.78 eV
- Long life
- Compact

Applications

- Mass spectrometry
- Environmental analysis
  - Gas detection

Schematic diagram of mass spectrometry



Specifications

Parameter		Specification	Unit
Window material		MgF_2	-
Spectral distribution		115 to 400	nm
Output stability at 230 nm	Drift (max.)	±0.25	%/h
	Fluctuation (p-p) (max.)	0.05	%
Guaranteed life*1 at 230 nm		1,000	h
Type number of power supply		C10707	-

*1 Life end is defined as the time when the light output intensity at 230 nm falls to 50 % of its initial value or when output fluctuations exceed 0.05 % (p-p).

Medical Life Science Drug Discovery Measurement Analytical Semicon Prod. Optical Comms Security Industry ND Inspection Academic Res.

20 W Xenon Flash Lamp Module L12745 Series

NEW

High output of 20 W
High repetition operation

The L12745 series is a 20 W xenon flash lamp module integrated with a regulated drive power supply and a lamp trigger socket. The light-emitting point of the lamp is preadjusted so the L12745 can be easily installed into equipment.

Features

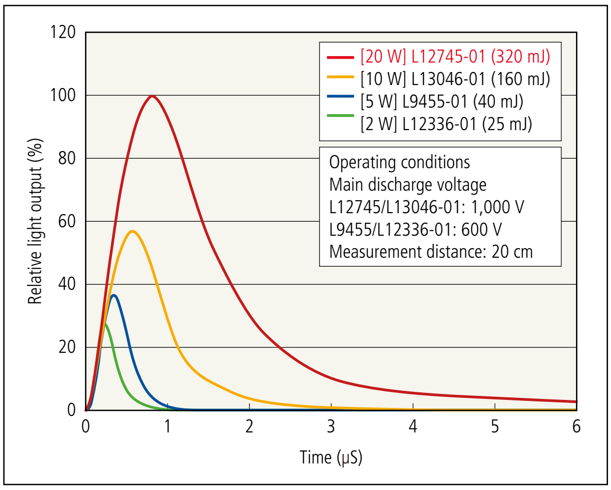
- High output power 20 W
- High stability
- High repetition operation
- Preadjusted light-emitting point

Applications

- Spectrophotometry
- Environmental analysis
  - Water quality and pollution analysis
  - Air pollution analysis
  - Laboratory testing
  - Urine analysis
  - Blood analysis
- Semiconductor inspection

L12745 series

Emission pulse waveform

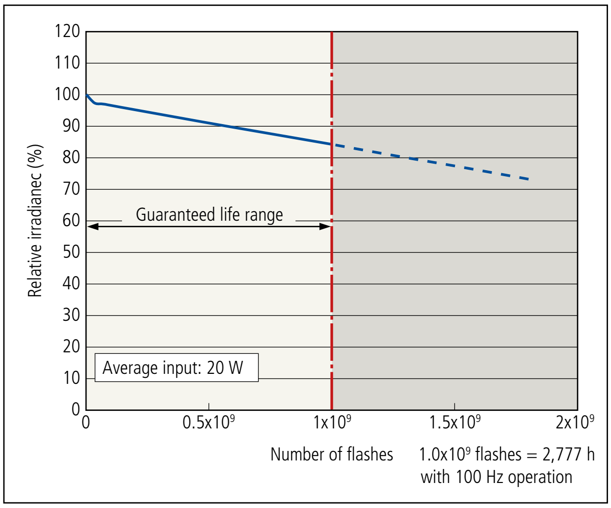


Specifications

Parameter	L12745			Unit
	-01	-02	-03	
Light output spectral range	185 to 2,000			nm
Main discharge voltage variable range	300 to 1,000			V
Main discharge capacitance	0.64	0.32	0.1	µF
Maximum average input (continuous)	20			W
Light output stability (typ.)	1			% CV
Guaranteed life*1	1×10^9			flashes
Maximum repetitive emission frequency	391	781	1,000	Hz

*1 20 W operation, at 791 V, 0.64 µF, 100 Hz

Life characteristics



NEW

Excimer Lamp Light Source "FLAT EXCIMER™" EX-86U L13129

Modification, cleaning and bonding with light

Unlike the excimer lamps of other manufacturers, our FLAT EXCIMER light source uses a flat lamp that ensures uniform irradiation. Processing by light (vacuum UV light at 172 nm) does not cause damage to objects, dust particle generation, or processing unevenness, which are usually caused by corona/plasma discharge methods.

Compared to our current in-line type (EX-400), the L13129 is more compact, lightweight and contains a power supply so that it can be easily installed almost anywhere without installation hassles. These features make it simple to incorporate the L13129 into existing production lines.

L13129

Features

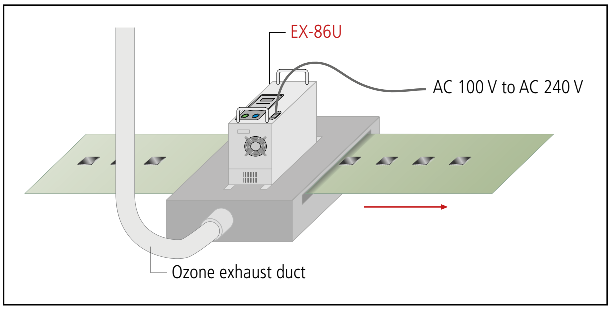
- No damage to objects
- No generation of dust particles
- Uniform irradiation
- Instantaneous ON/OFF
- Long life
- Less flickering


Irradiation area

Applications

- Surface modification
  - Pretreatment for adhesives (adhesive strength improvement)
  - Coating/printing adhesion improvement
- Material dry cleaning
  - Silicon wafer and glass substrate cleaning
  - Removal of organic films/adhesive residues
- Bonding of microfluidic devices

Installation example



Ozone is formed in air irradiated with vacuum UV light, so we ask that customers install exhaust air ducts that enclose the unit as shown in the example. The E12685 ozone decomposition unit (option) requiring no exhaust air duct can be used under certain conditions, depending on the installation environment and conditions.

Specifications

Parameter	Specification	Unit
Emission wavelength	172	nm
Irradiance*1	50	mW/cm²
Lamp design life	2,000	h
Irradiation area (W x H)	86 x 40	mm

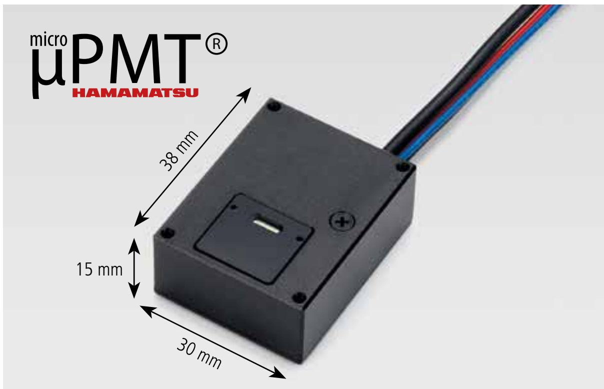
*1 Value calculated on the assumption that the irradiance is measured with a Hamamatsu UV power meter C9536/H9535-172 placed in the immediate vicinity of the lamp.

Micro PMT Photon Counting Head H12406/-01

NEW

Contains the world's smallest*, thinnest and lightest photomultiplier tube Capable of photon counting measurement

The H12406 and H12406-01 contain the world's smallest photomultiplier tube, "micro-PMT" together with a high voltage power supply and a photon counting circuit. Photon counting measurement can be performed by supplying +5 V. Two kinds of photocathodes (bialkali and multialkali) are selectable.
The cubic volume is about 1/2 compared to a metal package photomultiplier tube (H10682), so will help reduce equipment size.



H12406/-01

Features

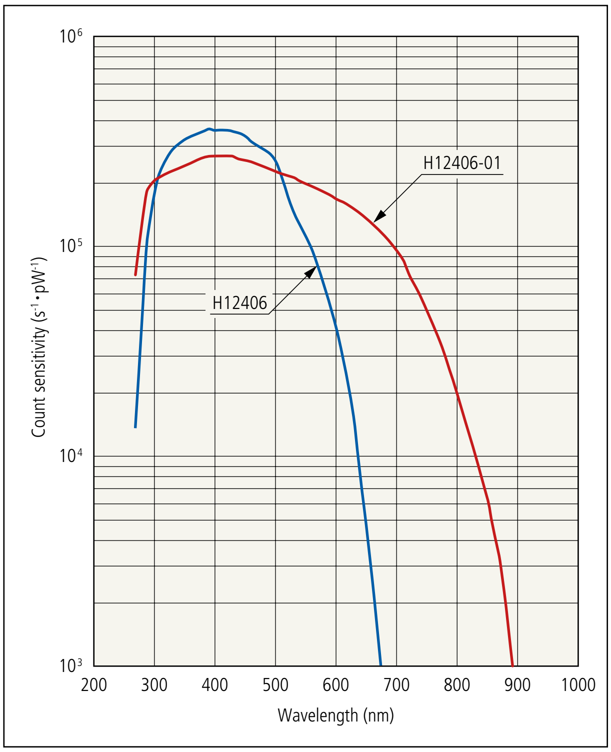
- Low voltage (+5 V) operation

Applications

- Portable medical devices
- Portable environmental measurement devices
- Hygiene monitoring system, etc.

* As of Oct. 2015, based on our research

Count sensitivity characteristics



Specifications

Parameter	H12406	H12406-01	Unit
Spectral response range	300 to 650	300 to 850	nm
Effective photocathode area (X x Y)	3 x 1		mm
Input voltage	+5		V
Count linearity*1	5×10^6		s^{-1}
Dark count (typ.)	10	100	s^{-1}
Pulse-pair resolution	20		ns
Output pulse width	10		ns
Output pulse height (typ.)*2	+2.2		V

*1 Random pulse, at 10 % count loss
*2 Input voltage +5 V, load resistance 50Ω

NEW

Photomultiplier Tube Assembly H13175U-01/20/110

Head-on photomultiplier tube assembly with the shortest overall length

The H13175U-01/20/110 are photomultiplier tube assemblies using a TO-8 metal-package photomultiplier tube R9880 integrated with a voltage divider circuit. The overall length of these photomultiplier tube assemblies is shorter than the length of the R9880U combined with a D-type socket assembly, so helps reduce equipment size.

H13175U-01/20/110

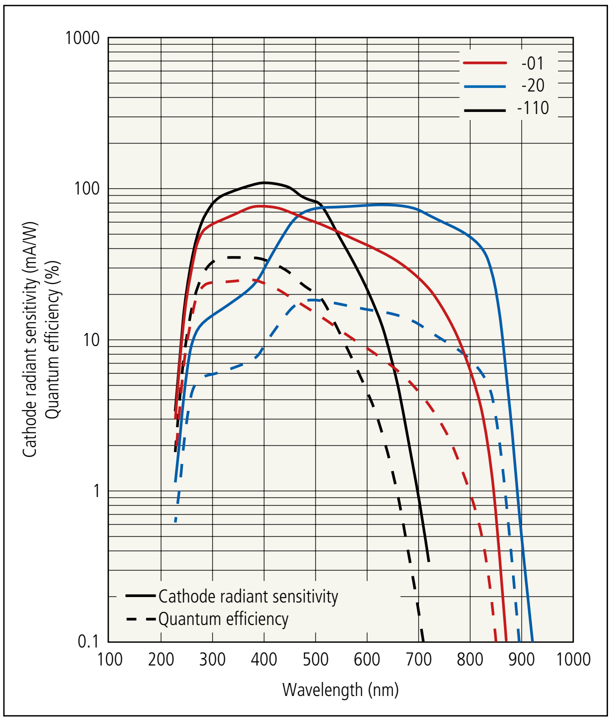
Features

- Compact and light weight: 7.5 g
- High gain

Applications

- Portable medical devices
- Portable environmental measurement devices
- Hygiene monitoring system, etc.

Spectral response



Specifications

Parameter	H13175U-01	H13175U-20	H13175U-110	Unit
Spectral response range	230 to 870	230 to 920	230 to 700	nm
Effective photocathode area		φ8		mm
Max. supply voltage		1,100		V
Voltage divider resistance		3.46		MΩ
Max. voltage divider current		0.32		mA
Cathode luminous sensitivity (typ.)	200	500	105	µA/lm
Gain (typ.)*1		2×10^6		-
Dark current (typ)*1	1	10	1	nA
Rise time		0.57		ns

*1 Supply voltage 1,000 V

High Speed HPD (Hybrid Photo Detector) Assembly H13223-40

NEW

Photodetector with high-speed response, high sensitivity, and low afterpulsing

HPD is a unique photomultiplier tube that contains a semiconductor device in the electron tube (vacuum tube). In a HPD, photoelectrons from the photocathode are accelerated to directly impinge on the semiconductor device where the photoelectrons are multiplied. This electron multiplication is efficient and generates less noise. The H13223-40 HPD has connectors to allow safe and easy connection to any length of cable. We also provide the C12929 power supply specifically designed for the HPD, which outputs a high voltage and reverse bias voltage necessary to operate a HPD. The high voltage and reverse bias voltage can also be externally controlled by input of control voltage.

H13223-40

Left: HPD assembly H13223-40, right: Power supply C12929

Features

- Fast time response
- Low afterpulsing
- High sensitivity
- Excellent time resolution

Applications

- Laser scanning microscope
- FCS (fluorescence correlation spectroscopy)
- LIDAR (light detection and ranging)
- TCSPC (time-correlated single photon counting)

Specifications

Parameter	H13223-40	Unit
Spectral response	300 to 720	nm
Photocathode material	GaAsP	-
Effective photocathode area	φ3	mm
Quantum efficiency at 500 nm	45	%
T.T.S.*1	90	ps
Rise time	400	ps
Gain (typ.)	1.2×10^5	-

*1 At the single photon state and the full illumination on photocathode, specified as FWHM (Full Width at Half Maximum). These values include the jitter of the electronics of about 30 ps.

Specifications

Parameter		C12929	Unit
High voltage	Max. output voltage	-8.5	kV
	Max. output current	16	μA
Diode bias voltage	Max. output voltage	±500	Vdc
	Max. output current	500	μA

NEW

Head-on Type Photomultiplier Tube/Assembly R12421-300 and H12690-300

Enhanced green sensitivity at 500 to 700 nm

The R12421-300 is a 13 mm (1/2 inch) diameter head-on photomultiplier tube with enhanced green sensitivity (quantum efficiency is 14 % at 550 nm while that of the current product is 8 %). The H12690-300 is a photomultiplier tube assembly incorporating the R12421-300, together with voltage divider circuit, HA treatment and magnetic shield.

Features

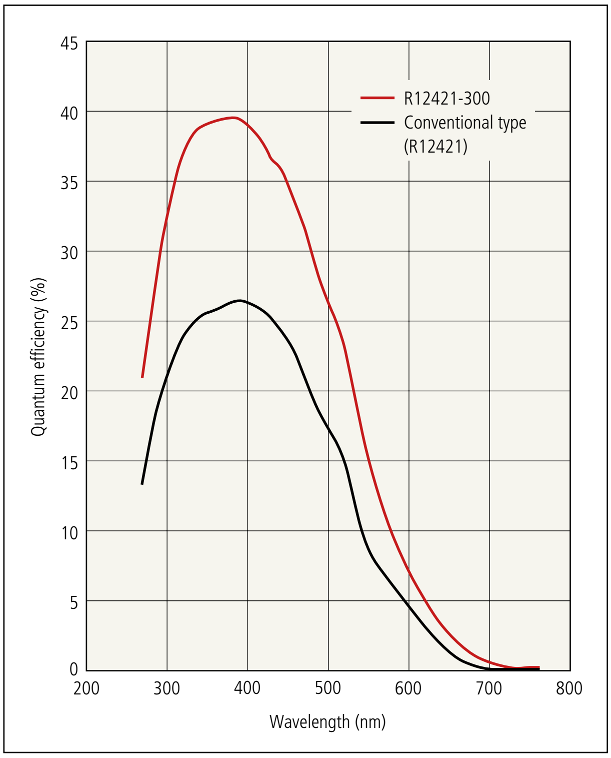
- High quantum efficiency: 14 % at 550 nm
- Compact
- Low dark counts
- Good PHD and plateau characteristics

Applications

- Photon counting
  - Hygiene monitoring
  - Clinical testing
  - Fluorescence/bioluminescence observation
- Scintillation counting
  - Survey meters

Left: R12421-300, right: H12690-300

Quantum efficiency



Specifications

Parameter	Specification	Unit
Spectral response range	300 to 700	nm
Photocathode type	Extended green bialkali	-
Quantum efficiency at 550 nm	14	%
Effective photocathode area	φ10	mm
Gain (typ.)*1	2×10^6	-
Dark counts (typ.)*1	400	s^{-1}

*1 Supply voltage 1,000 V, at 25 deg. C.

Side-on Type Photomultiplier Tube R13194

NEW

Solar-blind spectral response

The R13194 is a 13 mm (1/2 inch) side-on photomultiplier tube which offers around 5 times improved solar blindness, compared to a conventional product (R10825). The anode radiant sensitivity ratio (121 nm / 300 nm) is increased from 1,500 to 8,500, and so helps to enhance equipment performance.

Features

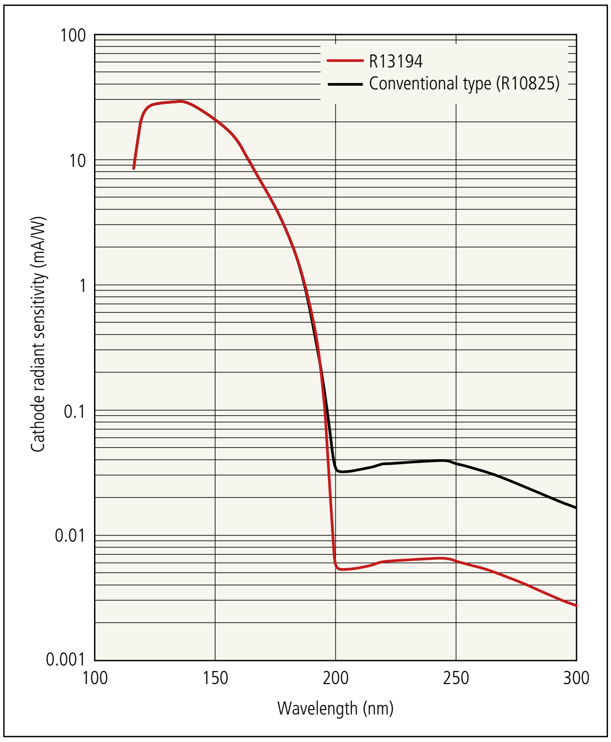
- Solar-blind spectral response
- High stability in VUV region
- Low dark current
- High VUV quantum efficiency

Applications

- Emission spectroscopic analysis
- Plasma emission measurement

R13194

Spectral response



Specifications

Parameter	Specification	Unit
Spectral response range	115 to 195	nm
Cathode radiant sensitivity at 121 nm	25.5	mA/W
Anode radiant sensitivity at 121 nm*1	1.0×10^5	A/W
Quantum efficiency at 121 nm	26	%
Anode sensitivity ratio 121 nm/300 nm*1	8,500	-
Anode dark current*1	0.05	nA
Gain (typ.)*1	3.9×10^6	-

*1 Supply voltage 1,000 V, at 25 deg. C.

NEW

Side-on Type Photomultiplier Tube R13456

Extended near-infrared sensitivity

The R13456 is a 28 mm (1-1/8 inch) diameter side-on photomultiplier tube. The limiting wavelength in the near infrared region is extended from 900 nm, compared to our current product (R928), to 980nm and sensitivity at 900 nm is 100 times higher than the R928. This makes the R13456 ideal for precision photometry, where high sensitivity in the near-infrared region is required.

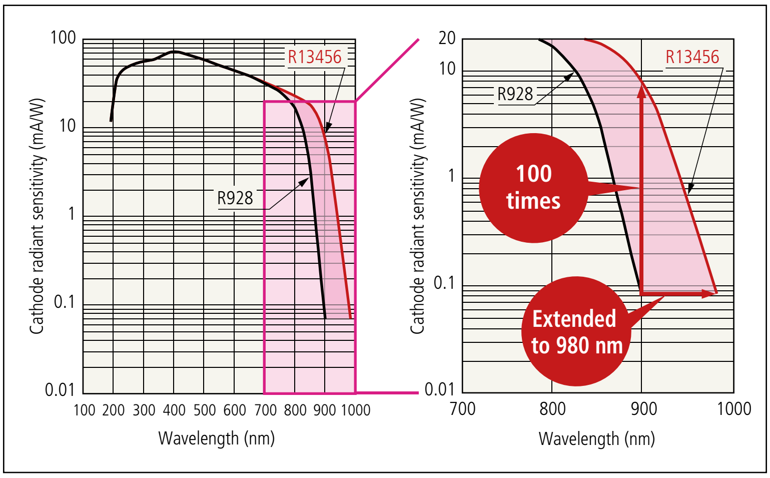
Features

- Wide spectral response
- High sensitivity at 900 nm (100 times higher than conventional type)

Applications

- Spectrophotometer (fluorescence, UV-VIS-NIR)
- Microscope
- Atomic absorption spectrophotometer
- NOx monitor

Spectral response



R13456

Specifications

Parameter	Specification	Unit
Spectral response range	185 to 980	nm
Cathode luminous sensitivity	280	μA/lm
Anode luminous sensitivity*1	2,800	A/lm
Anode dark current*1, 2	5	nA
Cathode radiant sensitivity at 900 nm	7.3	mA/W
Quantum efficiency at 900 nm	1	%

*1 Supply voltage 1,000 V, at 25 deg. C.
*2 After 30 min storage in darkness

Photomultiplier Tube Module H13320 Series

NEW

Low power consumption, battery operation available

The H13320 series is a 13 mm (1/2 inch) side-on photomultiplier tube module with a high-voltage power supply circuit and output cables. The current consumption is reduced to about one-eighth that of the currently available product (H9305), making the H13320 series ideal for portable instruments.

Features

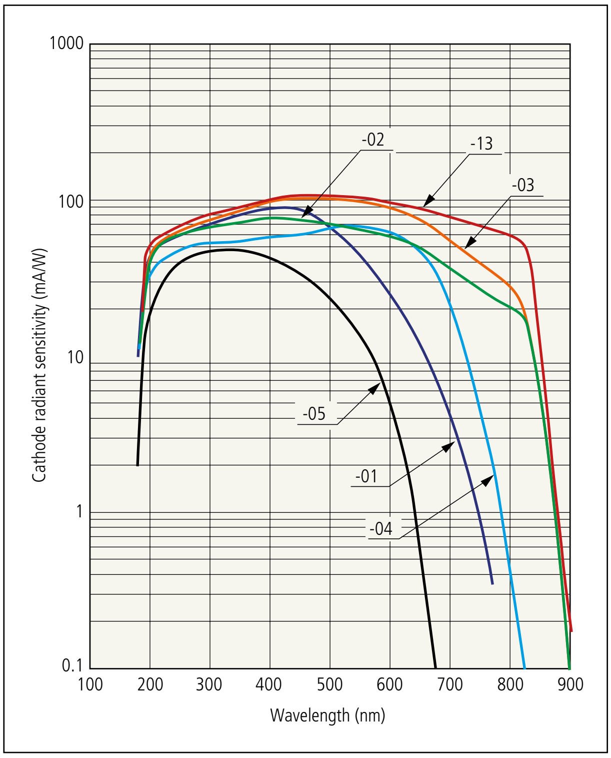
- Low power consumption
- Battery operation available (+3 V)

Applications

- Portable medical devices
- Portable environmental measurement devices, etc.

H13320 series

Spectral response



Specifications

Parameter	Specification	Unit
Effective photocathode area (X x Y)	3.7 x 13	mm
Input voltage	+3 to +5	V
Max. input current*1	2.7	mA
Max. output signal current	10	μA
Ripple noise*2 (p-p) (max.)	0.5	mV
Settling time*3	14	s

*1 Input voltage +5 V, control voltage +1.0 V, operated in darkness
*2 Control voltage = +1.0 V
*3 The time required for the output to reach a stable level following a change in the control voltage from +1.0 V to +0.5 V.

NEW

Photon Counting Head H13467 Series

Low power consumption, excessive light detection output

The H13467 series is a square-shaped photon counting head that contains a 25 mm (1 inch) diameter head-on photomultiplier tube, high-voltage power supply circuit and photon counting circuit. The H13467 series also includes a wide-band circuit to deliver high count rate performance. The high voltage for the photomultiplier tube and the discriminator setting are preadjusted to optimal levels, so photon counting measurement can start just by supplying +5 V. The H13467 can be easily installed in equipment by screw, due to its square-shaped case and compact overall length.

H13467

Features

- Low power consumption
- Excessive light detection output

Applications

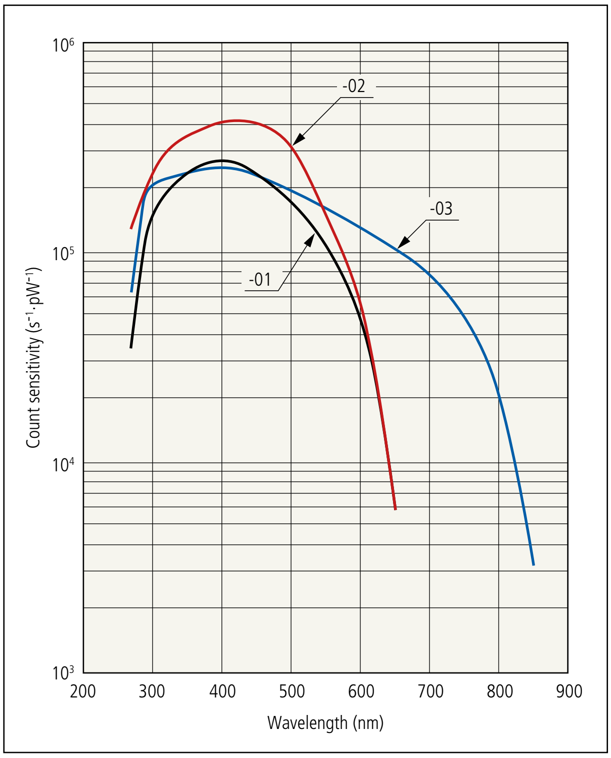
- Blood analyzer

Specifications

Parameter	H13467-01	H13467-02	H13467-03	Unit
Spectral response range	300 to 650		300 to 850	nm
Effective photocathode area	φ22			mm
Count linearity*1	6 x 10^6			s^{-1}
Input voltage	+5			V
Dark count (typ.)	15	60	5000	S^{-1}
Pulse-pair resolution	18			ns
Output pulse width	9			ns
Output pulse height (typ.)*2	+2.2			V

*1 Random pulse, at 10 % count loss.
*2 Input voltage +5 V, load resistance 50Ω

Count sensitivity



Wide Dynamic Range Photomultiplier Tube Unit H13126, C12918 Series

NEW

Photomultiplier tube unit that can measure with wide dynamic range up to 8 digits

This unit is capable of measuring light levels over a wide dynamic range of up to 8 orders of magnitude, by simultaneously extracting a digital output (photon counting) for detecting low level light and an analog output for detecting higher light levels visible to the human eye. This unit is designed to connect to a PC via a USB interface.

Features

- Measurement from single photon region to analog region
- Wide dynamic range measurement without changing photomultiplier gain
- USB interface for connection to PC for measurement and data acquisition

Applications

- Blood analyzer
- Luminometer
- Fluorescence measurement device
- Semiconductor inspection system
- MTP reader
- LIDAR (light detection and ranging)

Left: Wide dynamic range photomultiplier tube module H13126
Right: Data acquisition unit C12918 series

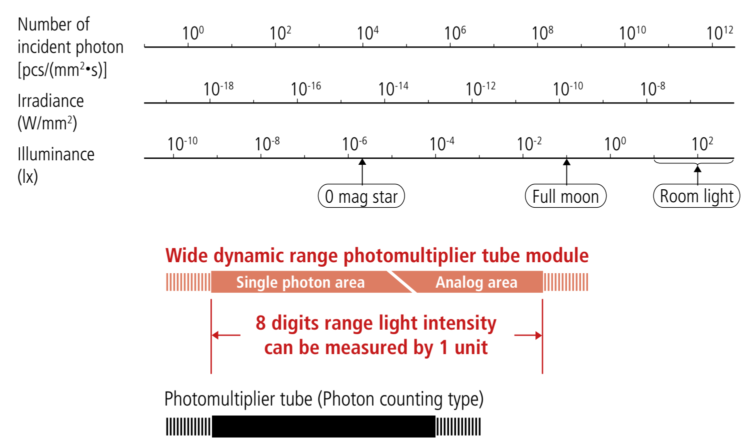
Specifications

Parameter		H13126	Unit
Photocathode effective area		φ22	mm
Spectral response range		300 to 650	nm
Photon counting dark count (typ.)*1		Below 100	s^{-1}
Analog (Amplifier output)	Bandwidth (-3 dB)	DC to 50/DC to 500	kHz
	Output voltage*2	0 to +10	V

*1 After 3 hours storage in darkness.
*2 Load resistance 1 kΩ.

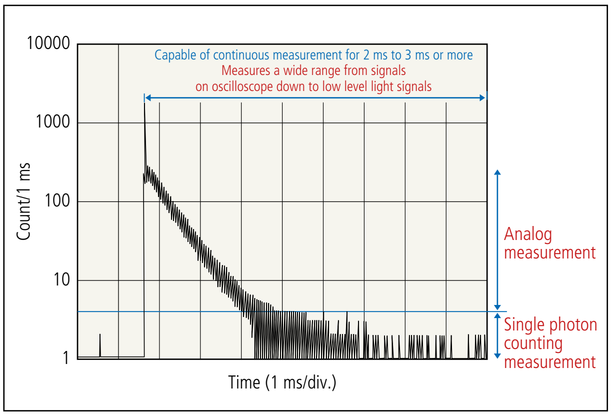
Parameter	C12918 series	Unit
Counter gate time	1 μs/10 μs	-

Light intensity



Correlation between number of incident photon and irradiance and illuminance when the light is λ = 555 nm

Measurement example: afterglow characteristics of P43 phosphor



NEW

High Voltage Power Supply Module C12766-12

Approved to UL 60601-1
-1,500 V/30 mA output

The C12766-12 provides a maximum output of -1500 V at 30 mA which is the highest output current among our high voltage power supply modules. The C12766-12 allows operation of multiple photomultiplier tubes with a single unit, making it ideal for PET and high energy physics experiments. The C12766-12 is our first high voltage power supply to be approved to UL 60601-1 Medical Electrical Safety Standard.

C12766-12

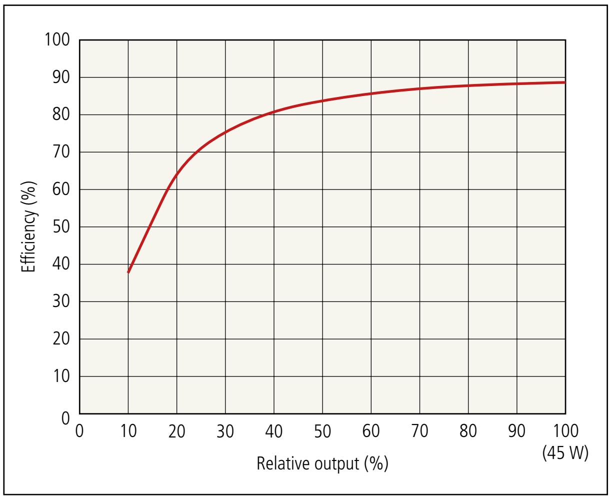
Features

- Approved to UL 60601-1 Medical Electrical Safety Standard
- High efficiency and less heat generation
- High stability

Applications

- Photomultiplier tube operation for PET diagnostic system
- Photomultiplier tube operation for high energy physics experiments

Efficiency characteristics



Specifications

Parameter	Specification	Unit
Maximum output voltage	-1,500	V
Maximum output current	30	mA
Ripple/noise (p-p) (Typ.)*1, 2	75	mV
Line regulation (Typ.)*1, 2, 3	±0.01	%
Load regulation (Typ.)*1, 4	±0.01	%
Input voltage	+24±1.2	V
Protective functions	Units protected against reversed power input, reversed/excessive controlling voltage input, continuous overloading/short circuit in output	-

*1 at maximum output voltage
*2 at maximum output current
*3 against ±1.2 V input change
*4 against 0 % to 100 % load change

Optical NanoGauge Thickness Measurement System C13027-02

NEW

10 nm to 100 µm thin film high speed measurement

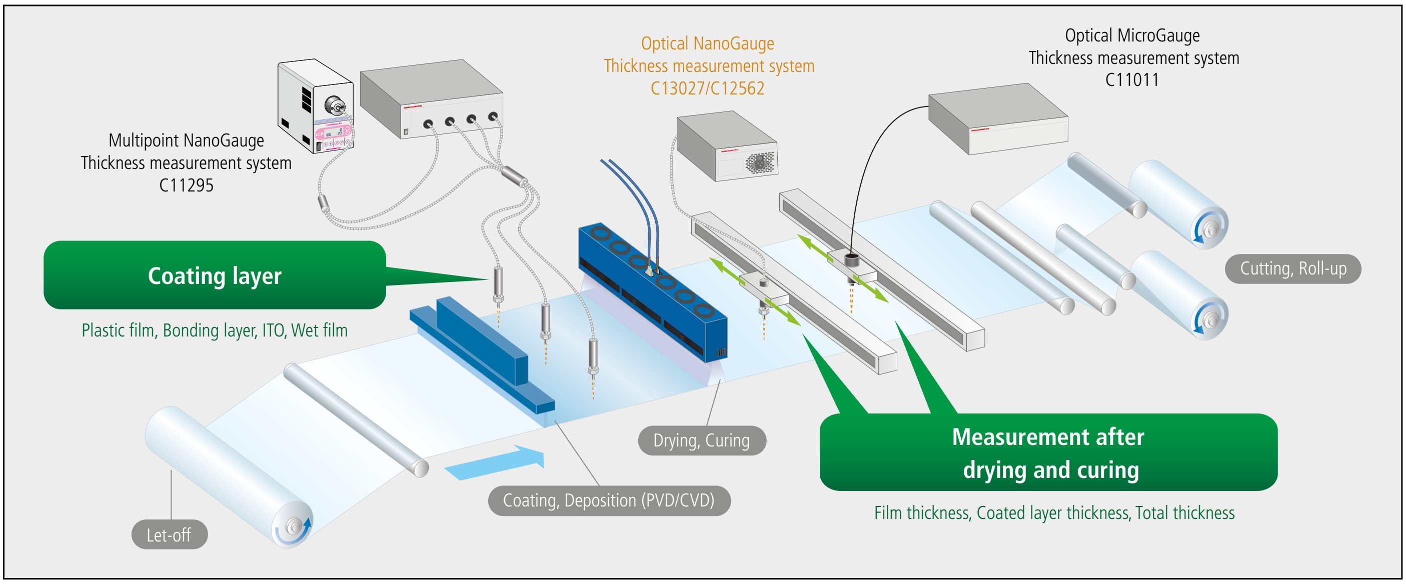
The Optical NanoGauge Thickness measurement system is a noncontact film thickness measurement system utilizing spectral interferometry. This new model supports connections to a PLC and and can be easily installed into production equipment.

C13027-02

Features

- Supports PLC connections
- Shortening of cycle time (max. 200 Hz)
- Capable of measuring 10 nm thin films
- Simultaneously measures thickness and color
- Downsized (footprint reduced by 30 % compared to C12562)
- Covers broad wavelength range (400 nm to 1,100 nm)
- Simplified measurement is added to the software
- Can measure both adverse side and reverse side of a film
- Precise measurement of fluctuating film
- Analyze optical constants (n, k)

Example: In-line measurement settings for film coating system



NEW

NanoZoomer S210 Digital Slide Scanner C13239-01

A new NanoZoomer for whole slide imaging

The newly developed NanoZoomer S210 delivers high performance, and is capable of handling large numbers of slides, at a lower cost. This was achieved without sacrificing the high image quality and equipment reliability, which has made our NanoZoomer series popular with many users around the world.

C13239-01

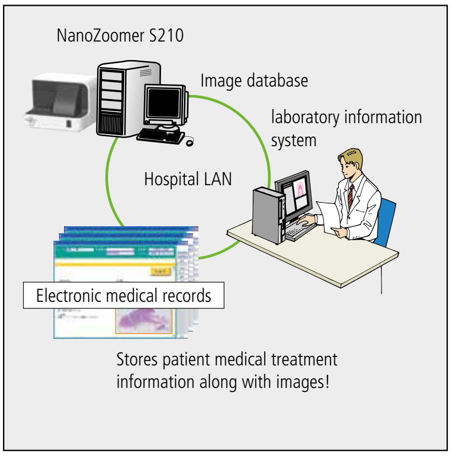
Features

- 210 slide capability
- Simple operation
- High performance

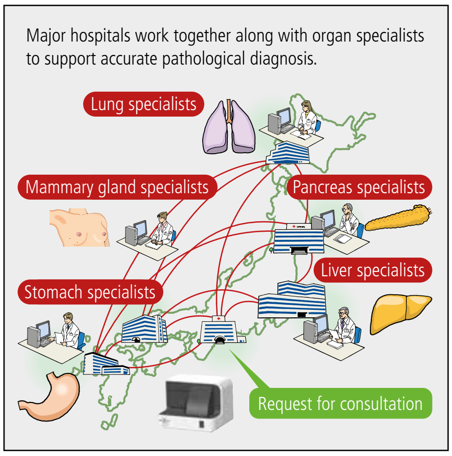
Applications

- Connecting with laboratory information system and electronic medical records
- Consultation
- Slide conferences, CPC (clinical pathology conferences)

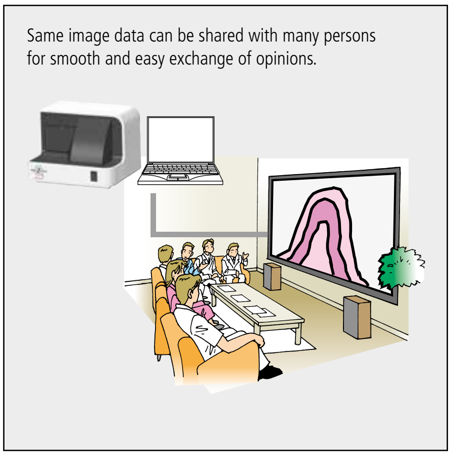
Connecting with laboratory information systems and electronic medical records



Consultation



Slide conferences, CPC (clinical pathology conferences)



NEW

InGaAs Camera C12741-03, C12741-11

High sensitivity in the near infrared region from 950 nm to 1,700 nm

The C12741-03 and the C12741-11 are InGaAs cameras with high sensitivity in the near infrared region. They can be used in a wide range of applications including silicon wafer inspection, laser beam alignment and evaluation of solar cells.

Features

- High sensitivity in the near infrared region from 950 nm to 1,700 nm
  640 × 512 pixels

C12741-03

- Simultaneous output both analog (EIA) and USB 3.0 ports
- Frame rate: 60 frames/s

C12741-11

- Low-dark current with -70 deg. C. peltier cooling requires (water-cooling)
- Air-cooling / water-cooling (interchangeable)
- Interface: Camera Link
- Frame rate: 7 frames/s

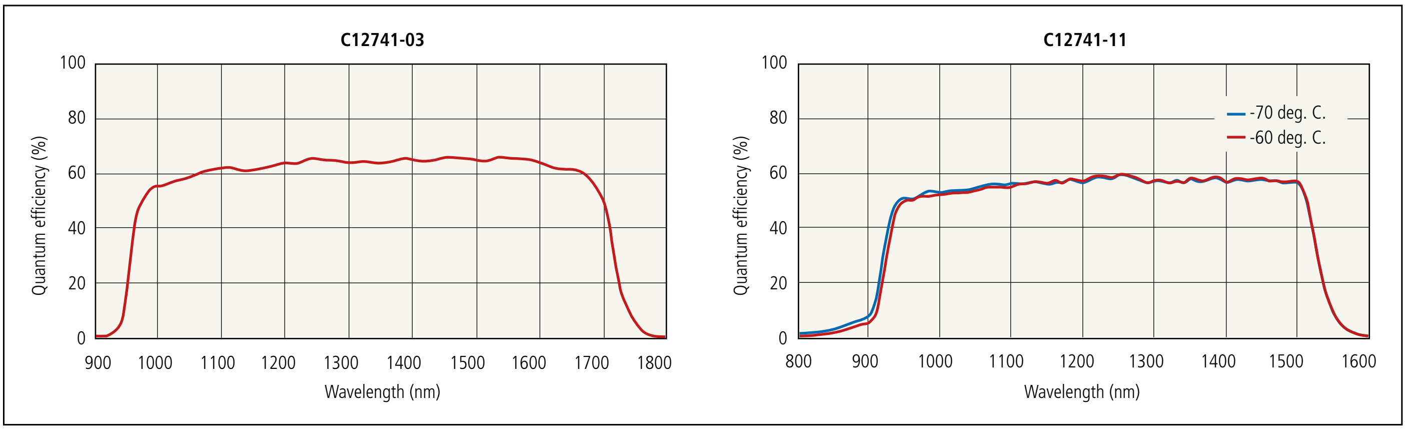
Applications

- Internal inspections of silicon wafers and devices
- Evaluation of solar cells
- Evaluation and analysis of optical communication devices
- EL/PL image acquisition

C12741-03

C12741-11

Spectral response



NIRO®-200NX DP

Quick and easy probe attachment with soft and lightweight, disposable probes

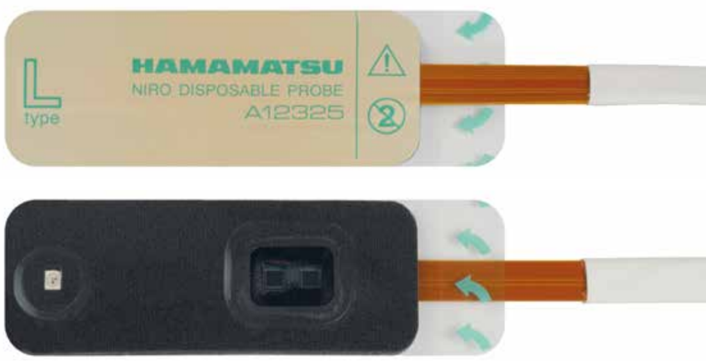
Simply peel off the outer seal and the probes are ready for use.

Soft and lightweight probes for user friendly attachment.

Smaller size probes available, designed to attach to smaller areas and compatible for simultaneous use with a monitor such as BIS.

Two types of probes available depending on the patients (adults and children).

S-type probe



L-type probe

EC REP
Hamamatsu Photonics Deutschland GmbH
Arzberger Str.10, D-82211 Herrsching, Germany
Telefon: +49 (8152) 375-201, Telefax: +49 (8152) 375-272

NEW

Fiber Output Laser Diode L13181-01

Fiber output laser diode with high environmental durability

The L13181-01 is a fiber output laser diode with high optical output (10 W) and high conversion efficiency (55 %) achieved by our unique device structure. The L13181-01 is an ideal high-luminance light source in a wide range of fields, including material processing, pumping of fiber lasers and solid-state lasers, medical treatment and chemical analysis.

L13181-01

Difference from conventional product

Package design emphasizes environmental durability.

Features

- 915 nm emission wavelength
- High output: 10 W
- High conversion efficiency: 55 % or more
- 0.15 NA, 105 µm core optical fiber
- Fiber coupled

Applications

- Direct condensing processing
- Fiber laser and solid-state laser pumping
- Medical treatment
- Chemical analysis

Specifications

Parameter	Symbol	Value	Notes
Output power at fiber exit end	Φef	10 W	
Operating current	I_{op}	11 A (typ.)	
Operating voltage	V_{op}	<2 V	
Emission wavelength	λc	915 nm ±20 nm	Contact Hamamatsu for other wavelengths
Guided wave longitudinal mode	-	Multimode	
Core diameter	-	105 µm	MM-S105
NA	-	0.15	Equivalent to 125-15 A
Jacket diameter	-	Φ0.25 mm	Bare optical fiber

Fiber Output Laser Diode L13421-01

NEW

Fiber output laser diode ideal for oxygen measurement

The L13421-01 is a semiconductor laser diode ideal for oxygen analysis. It delivers a stable oscillation wavelength and narrow linewidth via an optimized distributed feedback structure (DFB). Fiber output makes optical branching and lens coupling simple and easy. If any particular wavelength is required please feel free to contact us. (Designable center wavelength range is: 759 nm to 763 nm)

L13421-01

Difference from conventional product

We succeeded in producing a highly reliable 760 nm laser diode which was considered a very difficult task up to now.

Features

- 760 nm DFB pigtail
- Oscillation wavelength: 760.6 nm
- Wavelength linewidth: 13 MHz or less (typical value)
- Current dependence of wavelength shift: Approx. 0.004 nm/mA (typical value)
- LD temperature dependence of wavelength shift: Approx. 0.05 nm/deg. C. (typical value)
- Monitor PD/TEC inside

Applications

- Light source for oxygen monitor
- Medical instrument

Specifications

Parameter	Symbol	Min.	Typ.	Max.	Unit
Peak emission wavelength	λp	759.6	760.6	761.6	nm
Optical output	Φe	3	7	-	mW
Operating voltage	V_{op}	-	-	2	V
Emission mode	-	Single			-
Mode field diameter	-	4.5 to 5.5			µm

Conditions: I_{op} = 100 mA; $T_{op(c)}$ and $T_{op(ld)}$ = 25 deg. C.

NEW

CW Laser Diode L13421-04

High output power semiconductor laser ideal for oxygen measurement

The L13421-04 is a semiconductor laser diode ideal for oxygen analysis. It delivers a stable oscillation wavelength and narrow linewidth by optimizing the distributed feedback structure (DFB). If any particular wavelength is required please feel free to contact us. (Designable center wavelength range is: 759 nm to 763 nm)

L13421-04

Difference from conventional product

We succeeded in producing a highly reliable 760 nm laser diode which was considered a highly difficult task up to now.

Features

- 760 nm DFB
- Oscillation wavelength: 760.6 nm
- Wavelength linewidth: 13 MHz or less (typical value)
- Current dependence of wavelength shift: Approx. 0.005 nm/mA (typical value)
- LD temperature dependence of wavelength shift: Approx. 0.06 nm/deg. C. (typical value)

Applications

- Light source for oxygen monitor
- Medical instrument

Specifications

Parameter		Symbol	Condition	Min.	Typ.	Max.	Unit
Operating current		I_{op}	Φe = 20 mW	-	95	115	mA
Peak emission wavelength		λp	Φe = 20 mW	759.6	760.6	761.6	nm
Beam spread angle	Parallel	θ//	Φe = 20 mW FWHM	6	9	12	°
	Vertical	θ⊥		18	21	24	
Threshold current		Ith	-	-	65	85	mA

Conditions: $T_{op(c)}$ = 25 deg. C.

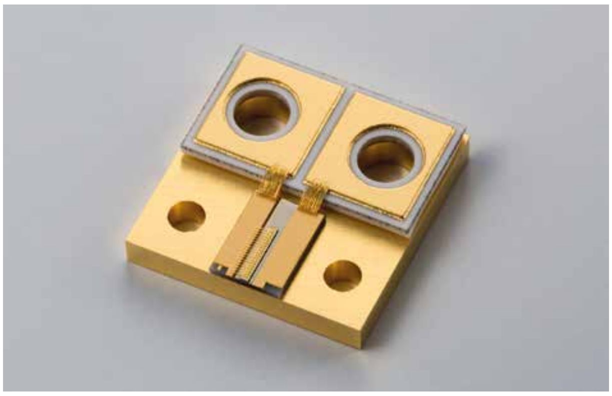
Medical Life Science Drug Discovery Measurement Analytical Semicon Prod. Optical Comms Security Industry ND Inspection Academic Res.

CW Laser Diode L13400, L13402

PRELIMINARY

Laser diode that delivers both high optical output and high conversion efficiency

The L13400 and L13402 are single emitter laser diodes achieving both high optical output power (12 W) and high conversion efficiency (L13400: 59 %, L13402: 55 %) by means of our unique device structure. These laser diodes use an F-mount package with a COS (Chip on submount) assembled on a flat open heatsink. This ensures good thermal contact with the heatsink and delivers high output power and high-reliability operation.



L13400, L13402

Difference from conventional product

These laser diodes offer the world's highest optical output and conversion efficiency levels.

Features

- 915 nm, 976 nm F-mount
- High output: 12 W
- High conversion efficiency:
  59 % (L13400)
  55 % (L13402)

Applications

- Direct condensing processing
- Fiber laser and solid-state laser pumping
- Medical treatment
- Chemical analysis

Specifications

Parameter		Symbol	Condition	Value		Unit
				L13400	L13402	
Threshold current		Ith	-	0.6	0.6	A
Operating current		I_{op}	12 W	12	12.3	A
Operating voltage		V_f	12 W	1.7	1.75	V
Beam spread angle (FWHM)	Parallel	θ//	12 W	10	10	°
	Vertical	θ⊥		25	25	
Peak wavelength		λp	12 W	915	976	nm
Emitter stripe width		W	-	90	90	μm

NEW

Quantum Cascade Laser

An optimum mid-infrared laser diode for molecular gas analysis

Quantum Cascade Lasers (QCLs) are semiconductor lasers that offer peak emission in the mid-IR range (4 μm to 10 μm). They have gained considerable attention as a new light source for mid-IR applications such as molecular gas analysis.

Difference from conventional product

Our lineup of QCLs now includes new products which emit light at long and short wavelengths.

Features

- Mid-IR laser (4 μm to 10 μm)
- Compact, lightweight

Applications

- IR molecular spectroscopy

DFB-CW type

DFB-Pulsed type

Specifications

Type No.	Wavelength	Wave number	Target gas
NEW L12004-2310H-C	4.33 μm	2,310 cm^{-1}	CO_2, CO_2 isotope
L12004-2209H-C	4.53 μm	2,209 cm^{-1}	N_2O
L12004-2190H-C	4.57 μm	2,190 cm^{-1}	N_2O, CO
L12005-1900H-C	5.26 μm	1,900 cm^{-1}	NO
L12006-1631H-C	6.13 μm	1,631 cm^{-1}	NO_2
NEW L12007-1392H-C	7.18 μm	1,392 cm^{-1}	SO_3
NEW L12007-1354H-C	7.39 μm	1,354 cm^{-1}	SO_2
L12007-1294H-C	7.73 μm	1,294 cm^{-1}	$^{12}CH_4/^{13}CH_4$

Specifications

Type No.	Wavelength	Wave number	Target gas
L12014-2231T-C	4.48 μm	2,231 cm^{-1}	N_2O, CO, CO_2
L12015-1901T-C	5.26 μm	1,901 cm^{-1}	NO
L12016-1630T-C	6.13 μm	1,630 cm^{-1}	N_2O
L12017-1278T-C	7.82 μm	1,278 cm^{-1}	CH_4, N_2O
NEW L12020-0993T-C	10.07 μm	993 cm^{-1}	NH_3

Fiber Output Laser Diode Bar Module L13705-20-940DA

NEW

Works with cooling units not requiring deionized water, making laser processing easy

The L13705-20-940DA is a compact, water-cooled laser diode bar module that boasts a high power of 200 W. This module uses distilled water for cooling and does not require deionized water. It can operate even under tough conditions such as low water flow, low water pressure, cooling water temperature of 25 deg. C. and is therefore easy to handle and use.

L13705-20-940DA

Difference from conventional product

It does not require chillers using deionized water.

Features

- High cooling efficiency
- Compact high-reliability package
- Allows cooling with distilled water (needs no deionized water)

Applications

- Solid state laser pumping
- Annealing
- Laser direct processing, etc.

Specifications

	Parameter	Value
General specifications	Radiant flux	200 W (CW)
	Laser class	Class 4
	Wavelength	940 nm ± 20 nm
	Dimensions (W x H x D)	Approx. 120 mm x 64 mm x 210 mm
	Weight	Approx. 3.7 kg
Other specifications	Applicable fiber core diameter	φ0.8 mm or φ0.6 mm
	N. A	0.2 ± 0.02
	Coolant	Distilled water

NEW

Pulsed Laser Diode Bar Module L13713-25P940

Rear water cooling ensures high luminance and simplifies installation

The L13713-25P940 laser diode bar module features a light weight, compact size and easily mounts into equipment. Laser diodes are eco-friendly since they deliver higher emission efficiency at lower energy, reducing running costs. The L13713-25P940 can also be designed for fast axis collimation as an option on request.

L13713-25P940

Difference from conventional product

Drastic boost in optical output from 100 W to 320 W per bar.

Features

- High optical power: 10 kW
- High stability
- Long life
- Light weight, compact

Applications

- Solid state laser pumping
- Fiber laser excitation

Specifications (tw = 400 μs, f_r*1 = 25 Hz, temperature of coolant: 20 deg. C., flow rate: 1.0 L/min)

Parameter		Symbol	Conditions	Min.	Typ.	Max.	Unit
Operating current		I_{op}	$\varphi_{ep} = 8.0$ kW	-	310	330	A
Center wavelength		λc	$\varphi_{ep} = 8.0$ kW	935	940	945	nm
Spectral radiation half bandwidth		Δλ	FWHM, $\varphi_{ep} = 8.0$ kW	-	5	8	nm
Forward voltage		V_{op}	$\varphi_{ep} = 8.0$ kW	-	45	60	V
Beam spread angle	Parallel	θ//	$1/e^2$, $I_{fp} = 300$ A*2	-	15	20	°
	Vertical	θ⊥			58	68	
Lasing threshold current		I_{th}	-	-	33	40	A

*1 Repetition frequency
*2 Measured with one bar (tw = 1 ms, f_r = 10 Hz, $T_{op(c)}$ = 25 deg. C.)

Global Exhibitions 2016


USA

April 2016

Advances & Breakthroughs in Calcium Signaling
April 7-9 2016, Honolulu, HI

BIOMEDevice
April 13-14 2016, Boston, MA

AACR
April 16-20 2016, New Orleans, LA

SPIE Defense & Commercial Sensing
April 19-21 2016, Baltimore, MD

ISA Symposium
April 24-28 2016, Galveston, TX

May 2016

The Vision Show
May 3-5 2016, Boston, MA

Radtech
May 16-18 2016, Chicago, IL

Pathology Informatics
May 23-26 2016, Pittsburgh, PA

June 2016

ASMS
June 5-9 2016, San Antonio, TX

CLEO
June 7-9 2016, San Jose, CA

CYTO
June 11-15 2016, Seattle, WA

July 2016

Semicon West
July 12-14 2016, San Francisco, CA

Digital Pathology Congress USA
July 14-15 2016, Philadelphia, PA

August 2016

ICHEP
Aug 7-10 2016, Chicago, IL

IMSC
Aug 20-26 2016, Toronto, ON

SPIE Optics & Photonics
Aug 28-Sept 1 2016, San Diego, CA

September 2016

SGIA
Sept 14-16 2016, Las Vegas, NV

CAP
Sept 25-28 2016, Las Vegas, NV

EUROPE

April 2016

Photonics Europe
April 5-6 2016, Bruxelles, Belgium

Photonex London Roadshow
April 11 2016, London, England

BSCB-BSDB Spring Meeting
April 11-12 2016, Coventry, England

Swiss Biotech Day
April 12 2016, Basel, Switzerland

Analytika
April 12-14 2016, Moscow, Russia

MINALOGIC
April 14 2016, Grenoble, France

MOST Forum
April 18-19 2016, Stuttgart, Germany

Affidabilità & Tecnologia 2016
April 20-21 2016, Torino, Italy

AKL
April 27-29 2016, Aachen, Germany

24. Jahrestagung der ADH
April 29-May 1 2016, Hildesheim, Germany

May 2016

E-MRS
May 2-6 2016, Lille, France

Diamond Light Source Monthly Supplier Exhibition
May 9 2016, Didcot, England

Sensor und Test
May 10-12 2016, Nuremberg, Germany

Analytica
May 10-13 2016, Munich, Germany

DigitalPath Europe
May 18-19 2016, London, England

Vårmöte Patologi
May 18-19 2016, Karlstad, Sweden

Pathologie Kongress 2016
May 19-21 2016, Berlin, Germany

SPS IPC Drives Italia 2016
May 24-26 2016, Parma, Italy

13th European Congress on Digital Pathology
May 25-28 2016, Berlin, Germany

DRUPA
May 31-June 11 2016, Düsseldorf, Germany

June 2016

Photonics Event
June 1-2 2016, Veldhoven, Netherlands

Optatec
June 7-9 Juni 2016, Frankfurt, Germany

Fotonica 2016
June 6-8 2016, Roma, Italy

3D Print Hub
June 7-9 2016, Milan, Italy

ENOVA
June 8-9 2016, Angers, France

Photonex Scotland Roadshow
June 8 2016, Edinburgh, Scotland

3rd FDSS Workshop
June 8 2016, Barcelona, Spain

12th FDSS Users Meeting
June 9 2016, Barcelona, Spain

29ème Congrès AFH
June 9-10 2016, Paris, France

WCNDT
June 13-17 2016, Munich, Germany

Connected Car & Mobility Expo
June 29-30 2016, Düsseldorf, Germany

July 2016

OPTIQUE
July 4-7 2016, Talence, France

11ème Congrès Européen de Neuropathologie
July 6-9 2016, Bordeaux, France

ICTON 2016
July 10-14 2016, Trento, Italy

Frontiers in BioImaging
July 14-15 2016, London, England

OSA
July 25-28 2016, Heidelberg, Germany

August 2016

European Microscopy Congress - EMC
Aug 28-Sept 2 2016, Lyon, France

Light Sheet Fluorescence Microscopy 2016
Aug 31-Sept 3 2016, Sheffield, England

September 2016

RICH 2016
Sept 5-9 2016, Bed, Slovenia

Photon16
Sept 6-7 2016, Leeds, England

Sindex
Sept 6-8 2016, Bern, Switzerland

E16
Sept 6-8 2016, Odense, Denmark

ENOVA
Sept 14-15 2016, Paris, France

MipTec
Sept 19-22 2016, Basel, Switzerland

ESREF
Sept 19-22 2016, Halle (Saale), Germany

14th Congress ESTP
Sept 20-23 2016, Barcelona, Spain

28th Congress of the ESP
Sept 25-29 2016, Cologne, Germany

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