Taking full advantage of **current technology**

Dr. Takashi Sato

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Diode lasers are one of the most important objects modern technology has to offer. Dr. Takashi Sato of Niigata University, in Japan, studies and creates devices based on diode lasers, thinking of ways to improve what we can do with this technology. The use of diode lasers to design better physical random number generators and optical communications systems are examples of his work.

What is your research background? How did this lead you to design diode laser devices and study their properties?

In 1960, I was a first-year elementary school student when I heard the news about the "best invention of the twentieth century" – the LASER (Light Amplification by Stimulated Emission of Radiation). That was when I decided I wanted to do some research on it. That was the beginning of it all.

Double optical feedback to a Vertical Cavity Surface Emitting Laser (VCSEL) – a type of laser with beam emission perpendicular to its top surface - seems like a very good prospect for future applications in optical communication systems. How did you come up with the idea for the project? Does this device plays any special role in current research?

As I was looking for ways to control diode lasers' oscillation frequencies without any active devices in its system, I found a paper that described a system using a double- instead of a single-optical feedback. I was also interested in VCSELs and finding ways to control their oscillation frequencies. The difficulties of introducing the VCSEL to the double optical feedback system seems to lay in VCSEL's highly reflective mirrors. And, even though the reflectivity of a Fabry-Perot etalon (a type of diode laser) is also very high, we can observe the transmitted light through it at its resonant mode. Therefore, we tried to introduce a VCSEL into our double optical feedback system.

If this device (or a modification) can be applied as a high-speed optical communication system light source, what do you think are the greatest implications of that for modern science and technology?

Both the VCSEL and its two-dimensional array structure demonstrate good multiplexing characteristics; this means a lot more data could be transmitted in several communication systems. Increasing the speed we transmit data, the possibilities are endless.

Why study random number generators? There are pseudo-random number generators. Why are the physical generators so much better?

Integers created by pseudo-random number generators can be decoded, given sufficient time. We must contend with the never-ending threat from hackers equipped with state-of-the-art computers, and advanced algorithms, who do everything in their power to access critical data. Currently, the high-speed generation of physical random numbers is one of the prospective means of accomplishing this.

Which of your research projects do you expect to be the most successful? Do you plan to extend this work further? In what direction do you plan to extend it?

Diode lasers, including the VCSEL-types, are marked by unique oscillation frequency characteristics, i.e., very fast frequency noise, so we need to be able to reduce and control it. Moreover, since they are so special, why can't we take full advantage of that? In upcoming experiments, I want to use these unique characteristics for fast physical random number generation, in a new type of rangefinder, and a light source that requires very wide frequency noise.

Making the best invention of the twentieth century better

Dr. Takashi Sato proposes several new applications and improvements to a very common device – the diode laser. The diode lasers are currently present in almost all things having to do with modern technology. From your Blu-ray player to fiber optic communications and laser surgeries, they are actually found in too many uses to list all of them.

SEVERAL RESEARCH SUBJECTS ON DIODE LASERS

One of the main works of Dr. Sato is using optical feedback techniques to diode lasers. Optical feedback is, by some way, redirecting the diode laser's own light to itself, such that the quality of the final beam improves, in the sense that the frequency line width becomes very small in comparison to the frequency emitted. This basically occurs due to several reflections producing standing wave patterns for certain resonance frequencies. Then you can adjust your setup to select the frequencies that you want. Dr. Sato and his collaborators designed a double optical feedback system applied to a Vertical Cavity Surface Emitting Laser (VCSEL) – a type of diode laser that has several advantages in fabrication, compared to the more conventional one.

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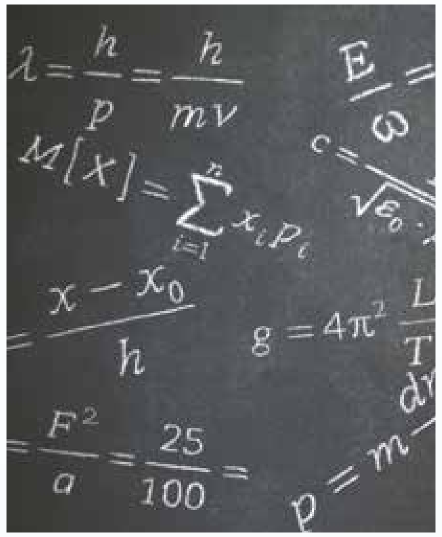
Another interesting fact about diode lasers is that they have a significant amount of quantum noise in optical power and frequency. Dr. Sato took advantage of that and proposed a novel method of generating physical random numbers using diode lasers' frequency noise. His proposed setup is believed to achieve very high speeds for generation of random numbers. This could lead to several applications, especially



in the area of cryptography and protection of computer systems.

DOUBLE OPTICAL FEEDBACK TO A VCSEL

VCSEL have many advantages compared to the usual edge-emitting semiconductor laser. First, their total fabrication cost is reduced and have better process control. Second, they can be built in two-dimensional arrays, providing new applications for lasers. They also have a lower power consumption. Even though the first VCSELs had lower power emission, there has been some advancements in this subject. However, its oscillation frequency line width is broader than the best edge-emitting lasers. Dr. Sato proposed setup has many significant advantages, particularly in narrowing the oscillation line widths.

Usually, VCSELs systems are not much sensitive to optical feedback, which can be an advantage in some applications, but, if you want a very narrow oscillation line width, you have to use an edge-emitting laser. With the double optical feedback of Dr. Sato, the oscillation line width obtained (2 MHz) is compared to typical edge-emitting laser with optical feedback. Their main objective is having VCSELs that may be applied to wavelength-division-multiplex – a form of optical communications system that can have several signals (with different wavelengths) within a single optical fiber. Then, without laying more fiber, network systems can improve their capacity of communication. Dr. Sato approach can have a great impact in the application of VCSELs to this kind of technology, making VCSELs a great prospect for high-speed optical communications systems light source, since the system is inexpensive.

What happens in a double optical feedback system is that you have three modes occurring: the internal mode of the diode laser and two external modes, due to the cavities created by the mirrors. Then, if you adjust your setup, you can make a total oscillation mode with a much narrower line width, that is, you use the additional external mode to control the unwanted behaviors of the first external mode.

Through many tests, using an extremely precise measurement experimental setup, Dr. Sato and collaborators showed that double optical feedback to a VCSEL has several advantages such as suppressing low frequency fluctuation, stabilizing oscillation frequencies and, of course, narrowing oscillation line widths. There is some limitations of course, such as the actual size of the experimental setup. Nevertheless, Dr. Sato and his collaborators are working on the perspective that it can be miniaturized.

RANDOM NUMBER GENERATION THROUGH DIODE LASERS' QUANTUM NOISE

Obviously, pseudo-random number generators are not random at all. They rely on algorithms, using mathematical formulae to produce sequences of numbers that appear random, but they are actually predetermined. Because these generators are fast, they are considered efficient. However, as they are deterministic, a sequence of numbers can be reproduced, given enough resources to a skilled hacker, for instance. Nevertheless, physical number generators are based on actual random physical phenomena, which makes the numbers really unpredictable. Unpredictable, but slow. The generation of random numbers through physical phenomena takes longer time than the pseudo ones. Dr. Sato and collaborators designed a device that promises to change this.

Diode lasers have something that we call quantum noise. Emission of radiation fluctuates spontaneously, due to the quantum nature of lasers. This causes several fluctuations in the physical properties of the laser, which in turn makes the optical power and frequency fluctuate. Since the initial fluctuation is random, all the others are. Then, if there are ways of measuring these quantum noises, you can feed them to a computer to generate random sequences of numbers. It is important to note that these numbers will be truly random (this is quantum mechanics after all…), it is the equivalent of giving dice for the computer to roll.

Dr. Sato investigated this behavior of diode lasers and concluded that the oscillation frequency of the laser changes very fast, which could be used to build a high-speed physical random number generator. Using a frequency discriminator, transforming the frequency fluctuation to an intensity fluctuation, which is easier to measure, the output beam then goes to a device that converts the data to 8-digit binary numbers. They are currently producing random numbers in a speed of 3 Gbit/s, but they believe they can do much better than that.

Besides generating true random numbers, Dr. Sato's group even designed an optical range finder using the characteristics of the laser's frequency fluctuation. They compared the random data from two signals that traveled through different optical paths, one of them reflecting at a target. Because these signals originate from the same beam, their random fluctuations are correlated. Computing this correlation makes possible to determine the time lag between the optical paths. The system was accurate to a distance of up to 50 m, at a resolution of 0.03 m.

Although you can find other uses for random number generators, its main purpose is making better encryption systems. High-speed physical generators, such as Dr. Sato's device, are an important improvement for this. Security of data is maybe one of the most important things on this century, for several reasons. Encryption of data benefits from this kind of research, because, since the numbers generated are truly random, they are the definition of unpredictable. None of its sequence can be reproduced on purpose, only by chance.

Researcher Profile

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Dr. Takashi Sato received his B.S., M.S. and Ph.D. in Electronic Engineering from Kyoto University. Dr. Sato aims to study and build devices, based on diode lasers, leading to applications in several fields, especially optical communications systems. He has done research with diode lasers in the subjects of frequency stabilization, oscillation frequency shift in magnetic fields, physical random number generators using frequency noise and optical range finders. His approach to diode lasers devices has the prospect of greatly improving optical and IT systems.

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