Technologies in fields such as optical devices, material science, and information science, at the true cutting-edge of a new era.

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Social Impact Assessment Method for ICT Services
(Gross Social Feel-good Index)

NTT Group is committed to the creation of a safe, secure and prosperous society through ICT* services. However, the degree to which ICT services help society become safe, secure and prosperous has not been quantitatively discussed. ICT services have strong effects on the environmental, social, and economic aspects of our lives, which are known collectively as the triple bottom line. These effects are not only positive but also negative; for example, the positive effect of security (“watchdog”) services is that they deter crime, but one of their negative effects is leaking information. If the negative effects exceed the positive effects when a particular ICT service is introduced, the service could be counterproductive to the creation of a safe, secure and prosperous society. Therefore, we have to assess ICT services quantitatively by taking account of their positive and negative effects.

We developed a “Gross Social Feel-good (GSF) index” to evaluate the contribution of ICT services to creating a safe, secure and prosperous society. The GSF index is composed of six sub-indexes, namely environment, safety, health, comfort, economy, and happiness. The concept of this index is that a society is sustainable when the triple bottom line requirements are satisfied and people feel happy. Here, the society aspect was expressed in three further sub-indexes of safety, health and comfort. With the GSF index, we can quantitatively assess the improvement in social sustainability achieved by introducing ICT services. In addition, indication of the negative effects of a service can help us to improve and/or redesign ICT services so that they can more effectively contribute to society.

Social impact assessment is new technical field that has become a focus of attention for development of a sustainable society, for example, resolution of global environmental problems. Although the GSF index was designed to assess ICT services introduced in Japan, we would like to extend its concept and promote its use worldwide as a standardized index for evaluating the sustainability of corporations, autonomous communities, and governments, as well as ICT services.

* ICT: Information and Communications Technology

Gross Social Feel-good index

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**Elements of sustainable society**

- **Environment**: Few environmental burdens (Environmental impact)
- **Safety**: People and/or their belongings are safe (Accidents, disasters, crime, information security)
- **Health**: Free from disease (Health care, disease, medical treatment, stress)
- **Comfort**: Comfortable life (Various opportunities, barrier free, simplicity, ubiquitous)
- **Economy**: Good cost-benefit performance (Cost-benefit performance)
- **Happiness**: Being happy (People’s satisfaction)

**Which effect is larger?**

Positive effects vs. Negative effects

**ICT services**

- Need to improve economy aspect.
- Profound effects on environment, safety and happiness aspects.
Accompanying the popularization of broadband services has been a growing expectation for a large-capacity optical transport network based on WDM\(^1\) technologies. Moreover, to provide future high-speed-transmission services, achieving ultra-high-speed transmission of 100 Gbit/s per wavelength is becoming a key challenge. In NTT Network Innovation Laboratories, by wavelength-multiplexing of 100-Gbit/s-class signals and by widening the available bandwidth and increasing transmission rate, we have successfully achieved large-capacity transmission of over 20 Tbit/s\(^2\).

As a modulation format suitable for high-speed, large-capacity transmission, multi-level phase modulation called CSRZ-DQPSK\(^3\) was applied. This modulation format enabled transmission rate double the operation speed of electrical circuits and improved the spectral efficiency. On realization of this method, in cooperation with NTT Photonics Laboratories, prototypes of a high-speed optical modulator, a digital IC, and a prototype of a balanced receiver were constructed, and an ultra-high-speed (i.e., 111 Gbit/s) receiver was implemented. Moreover, a P-EDFA\(^4\) and an extended-L-band amplification technique using a distributed Raman amplifier were developed, and the number of wavelengths was doubled in comparison to the conventional systems. As a result of applying these technologies, we are the first in the world to successfully accomplish transmission of a 14-Tbit/s signal along a single optical fiber (with a length of 160 km). This is the first time in five years that we have taken the record for transmission capacity. Furthermore, by upgrading the optical-amplification technology, we are successfully performing transmission experiments of 20-Tbit/s over 240-km-long optical fiber.

At NTT Laboratories, from now onwards, we will continue to advance research and development on WDM transmission technology aimed at realizing the large-capacity optical networks that will support future broadband services.

\(^{1}\) WDM: Wavelength Division Multiplexing  
\(^{2}\) Tbit: 10\(^{12}\) bits  
\(^{3}\) CSRZ-DQPSK: Carrier-Suppressed Return-to-Zero Differential Quadrature Phase Shift Keying  
\(^{4}\) P-EDFA: Phosphorous co-doped Erbium-Doped Fiber Amplifier

### 20-Tbit/s transmission experiment

- **20 Tbit/s signal (204 ch×111 Gbit/s CSRZ-DQPSK)**
- **Fiber (80 km)**
- **Raman pump**
- **InP MUX**
- **111 Gbit/s Tx**
- **InP MUX**
- **LD**
- **111 Gbit/s Rx**
- **PLC MZDI**
- **Balanced Receiver**
- **10.2 THz (84 nm)**
- **Optical power (to dB(dB))**
- **Received optical spectra and eye pattern**

*1 Tx: Transmitter  
*2 Rx: Receiver  
*3 InP MUX: Indium Phosphide Multiplexer  
*4 LD: Laser Diode  
*5 PLC MZDI: Planar Lightwave Circuit Mach-Zehnder Delay Interferometer
At NTT Photonics Laboratories, we have devised a hybrid integration technique for a silica-based PLC*1 (with excellent low-loss and design-freedom characteristics and long-term reliability) and LN*2 waveguide (with large electro-optical effect), and we have developed an ultra-high-speed DQPSK*3 modulator that can handle 100-Gbit/s transmission. In addition, in collaboration with NTT Network Innovation Laboratories, we have demonstrated the possibility of ultra-large-capacity transmission at 14-Tbit/s along a transmission distance of 160 km (111-Gbit/s x 70 channels x polarization multiplexing).

The prototype DQPSK modulator is composed of three substrates: a PLC-type 1 x 4 splitter, a four-array LN phase modulator chip, and a PLC-type 4 x 1 coupler with a thermo optic-effect phase shifter. The connection part between the PLC and LN is a feature that reduces connection loss and reflections generated at the interface between the PLC and LN. Furthermore, branching section in the splitter is designed by using the WFM*4 design developed by NTT, so low excess loss of less than 0.2 dB per branching point was accomplished even for a 1.5 % waveguides. Moreover, in regards to the optical characteristics of the modulator, adequate 100-Gbit/s DQPSK modulation characteristics (namely, insertion loss of 6.5 dB, extinction ratio of 26 dB, and E/O frequency bandwidth of 26 GHz) were obtained.

From now onwards, we will strive to improve the low-loss, a compactness of the module and the E/O frequency bandwidth. On top of that, after verifying the long-term reliability of the ultra-high-speed DQPSK modulator, we are aiming to put it to practical application.

*1 PLC: Planar Lightwave Circuit
*2 LN: Lithium Niobate
*3 DQPSK: Differential Quadrature Phase Shift Keying
*4 WFM: Wavefront Matching

External view of module and circuit configuration

* TO: Thermo Optic
In recent years, with the rise in people's consciousness regarding our environment, the development of a high-sensitivity gas sensor that enables in-situ and real-time gas sensing has been eagerly awaited. To fully satisfy this requirement, a gas sensor utilizing a telecom semiconductor laser for specific industrial applications is being implemented in Europe and the USA. However, in regards to expanding these industrial applications and promoting applications of such a sensor in medical and environmental fields, it is indispensable to further improve sensitivity by extending laser wavelength to the mid-infrared region (i.e., >2 \( \mu \)m). Accordingly, competition concerning research and development on a mid-infrared laser taking various approaches is intensifying; nevertheless, there is still no example of a successful development of a practical mid-infrared laser.

At NTT Laboratories, by optimizing the performance of all-optical simultaneous wavelength-converter made of lithium niobate—expected as a key device in future WDM* networks—at the mid-infrared region and combining the converter with telecom semiconductor lasers, we have developed a world-leading laser light source for generating stable, continuous-wave mid-infrared light in the 2-5-\( \mu \)m wavelength region at room temperature.

Furthermore, we used the developed mid-infrared laser for detecting environmental gases such as methane, carbon monoxide, and carbon dioxide, thereby validating the effectiveness of the laser for gas sensing. From now into the future, while promoting global marketing of mid-infrared lasers developed through cooperation with an NTT Group company, we will continue to advance development of gas sensors using our mid-infrared lasers for industrial and medical applications in collaboration with manufacturers in the USA.

What's more, as an example of differentiation technology for information-input appliances of networks, a gas sensor for detecting information not easily detected by other conventional sensor technologies is presently under development.

* WDM: Wavelength Division Multiplexing

Construction of the mid-infrared laser and detection of methane gas

![Construction of the mid-infrared laser and detection of methane gas](image)

*1 LD: Laser Diode  
*2 FBG: Fiber Bragg Grating  
*3 DFB-LD: Distributed Feedback Laser Diode  
*4 TE: Thermoelectric
Information presentation of haptic sensations (i.e., the sense of touch) on conventional mobile devices has been limited to vibratory perception stimulated by vibrator-like devices. Moreover, although the instantaneous turning force on a mobile device, such as that produced by twisting of the wrist, can be presented, directly and continuously presenting force in the translational direction has been impossible. This is because there is a physical limitation occurring when presenting kinesthetic and haptic sensations like unfixed feedback to the surroundings and because non-contact drive by magnetic and electric fields is not considered to be a practical method in a mobile environment. Consequently, actually generating a pulling (or pushing) sensation as a physical force has been impossible for all practical purposes.

In response to these problems, we have developed a method that creates an illusion of tractional force by utilizing the non-linearity of human sensations. This method involves creating periodical translational motion by means of combining sharp accelerated motion (in the form of pulses) on an outward route against a dead weight and accelerated motion along a slow return route to the initial position. The acceleration of this back-and-forth motion is generated under periodic motion, so the one-cycle integral naturally becomes zero. However, by keeping a bias between the times required for the outward and return recycles, movement with large differences in acceleration amplitude is created. Since force is proportional to acceleration, this motion is a way of generating an asymmetric force. Humans possess the sensory characteristic of not easily sensing a gradually applied force, so the above-described succession of forces can create the illusion of a force pulling in either direction. In a prototype interface model, a link mechanism that linearly reciprocates a mass back and forth is utilized. As a result, a successively pulsed stimulation in the direction in which an acceleration reaction force with large amplitude is felt in a short time was successfully presented. We are presently investigating the effective conditions for creating this haptic presentation and clarifying the mechanism of the sensation illusion.

From now onwards, as well as evaluating the interface through hands-on experience, we plan to improve the acceleration-generation mechanism and make the interface more compact. Looking at the longer-term future, by fitting the interface as a module in devices such as mobile phones, we are aiming to realize “lead-by-the-hand” pedestrian navigation by combining the interface with a global positioning satellite (GPS) function. Moreover, we are also presently investigating walking assistance for visually impaired people.

Haptic interface using characteristics of human perception (Buru-Navi)
Statistical Machine Translation (SMT)

NTT Communication Science Laboratories

Statistical machine translation, hereafter referred to as SMT, is a novel technology that enables the automatic construction of a machine translation system by using statistical models, trained by large amount of text data. Because the algorithm used by SMT does not depend on a particular language, multilingualization is easy if we can obtain the training data for multi-languages, and robust systems can be constructed at a low cost in a short amount of time. Conventional machine translation systems are built by utilizing a language expert, who understands both the input and output languages, to define the translation rules. A rule-based translation method used in the conventional systems requires language experts. Consequently, it is difficult to deal with less common languages where an expert may be hard to find. Therefore, high development cost accompanies the difficulty of multilingualization. SMT is a method that enables automatic machine translation without the need for a language expert, as long as a large-volume of multi-language text data is available.

In the training text data, both bilingual text data and monolingual text data of the output language are used. The bilingual text data is a collection of sentences that expresses the same contents in the respective input and output languages. A translation model and a language model are trained from each data set, respectively. The translation process is accomplished by a process that utilizes the two statistical models and searches for probable word sequences from a vast hypothesis. Since successive processing does not depend on language or domain of the text, machine translation for any language in any domain can be easily achieved, so long as text data for training is available. As a result, SMT easily enables multilingualization as well as translation of specific domain, which has been difficult to accomplish with conventional rule-based translation. Newspapers, manuals, and public documents such as patents already have a vast amount of translations. Translation services specialized in each domain can thus be easily created by using each type of document for the training data.

SMT is still a growing technical field. Even though we have researched methods for speeding up the translation process and methods for properly modeling word order to improve translation accuracy at NTT Laboratories, more and more technical problems are accumulating. Consequently, we are currently engaged in basic research on these continuing challenges. In the meantime, we might be able to provide applicable translation services with the existing technology. In addition to doing this basic research, we are investigating in applications that utilize the SMT system.

Statistical machine translation

（Source language）伊藤博文は日本の首相でした。
（Target language）Hirobumi Itoh was the prime minister of Japan.
In recent years, communication capacity has rapidly increased. This situation demands high-density data-storage devices and high-speed signal-processing integrated circuits (ICs). To meet this need, an ultraviolet (UV) light source with a shorter wavelength is required for recording digital information more densely on optical storage devices and for nanometer-order patterning of ICs. Aluminum nitride (AlN) has the widest bandgap*1 among semiconductors. Therefore, it has been theoretically predicted that an AlN light-emitting device would emit ultraviolet light with the shortest possible wavelength for semiconductors.

NTT Laboratories have developed technologies for fabricating high-purity AlN crystals and have succeeded in p-type and n-type doping of this material, which is essential for light-emitting devices. Using these technologies, we fabricated an AlN light-emitting diode (LED) and measured ultraviolet light with a 210-nanometer*2 wavelength emitted from it. This is the shortest wavelength ever emitted from any semiconductor.

Because light with a shorter wavelength has a larger energy, the 210-nanometer light can efficiently decompose very stable harmful chemical substances, such as dioxin and polychlorinated biphenyls (PCBs), which cause serious environmental problems all over the world. Therefore, AlN UV-LEDs are expected to be used as light sources in environmental protection equipment.

We will increase the performance of AlN LEDs to a practical level by further improving their crystal quality and doping efficiency.

*1 bandgap: Energy peculiar to a semiconductor. The bandgap energy is inversely proportional to the wavelength of light emitted from a semiconductor.
*2 nanometer: one thousand millionth of a meter

AlN ultraviolet light-emitting diode (LED): Device structure and light emission characteristics

LED structure

Top view of LED

Ultraviolet light from LED: the shortest wavelength

*1 AlGaN: Aluminum Gallium Nitride
*2 SL: Superlattice
*3 SiC: Silicon Carbide
Single Electron Ammeter

A conventional sensitive ammeter requires millions of electrons to detect a current. It is desirable to be able to detect extremely small currents especially for studies that examine electron transport through nanostructures, single molecules, and biological cells.

Our single-electron ammeter with single-electron sensitivity integrates two quantum dots and a point contact in a semiconductor device, as shown in the upper-left figure. An electron entering or escaping from one of the quantum dots influences the current flowing through the point contact, and thus the change in the electron occupation in a quantum dot can be monitored. Two quantum dots are required in order to identify the direction from which the electron has entered or to which it has escaped. This bidirectional counting is essential for making a single-electron ammeter.

When an electron travels through the two quantum dots, the current through the point contact shows three different values depending on the location of the electron, as shown in the lower figure. Jumping between these values can be understood as, for example, (1) an electron entering the left dot, (2) moving to the right dot, and (3) escaping to the right lead. In this way, a single-electron flow can be detected precisely and the average current can be obtained by counting the net electron flow. The current noise in the demonstrated single-electron ammeter was 3 attoamperes* peak-to-peak, and is more than three orders of magnitude smaller than in a conventional current meter.

The single-electron ammeter should be especially useful for studies on nanoelectronics. Furthermore, statistical analyses of current noise measured with the single-electron ammeter would possibly identify intriguing correlations in electron currents.

* attoamperes: $10^{-18}$ one-billionth of a billionth ampere

Schematic diagram of the single-electron ammeter

SEM image of the device

Example measurement

500 nm