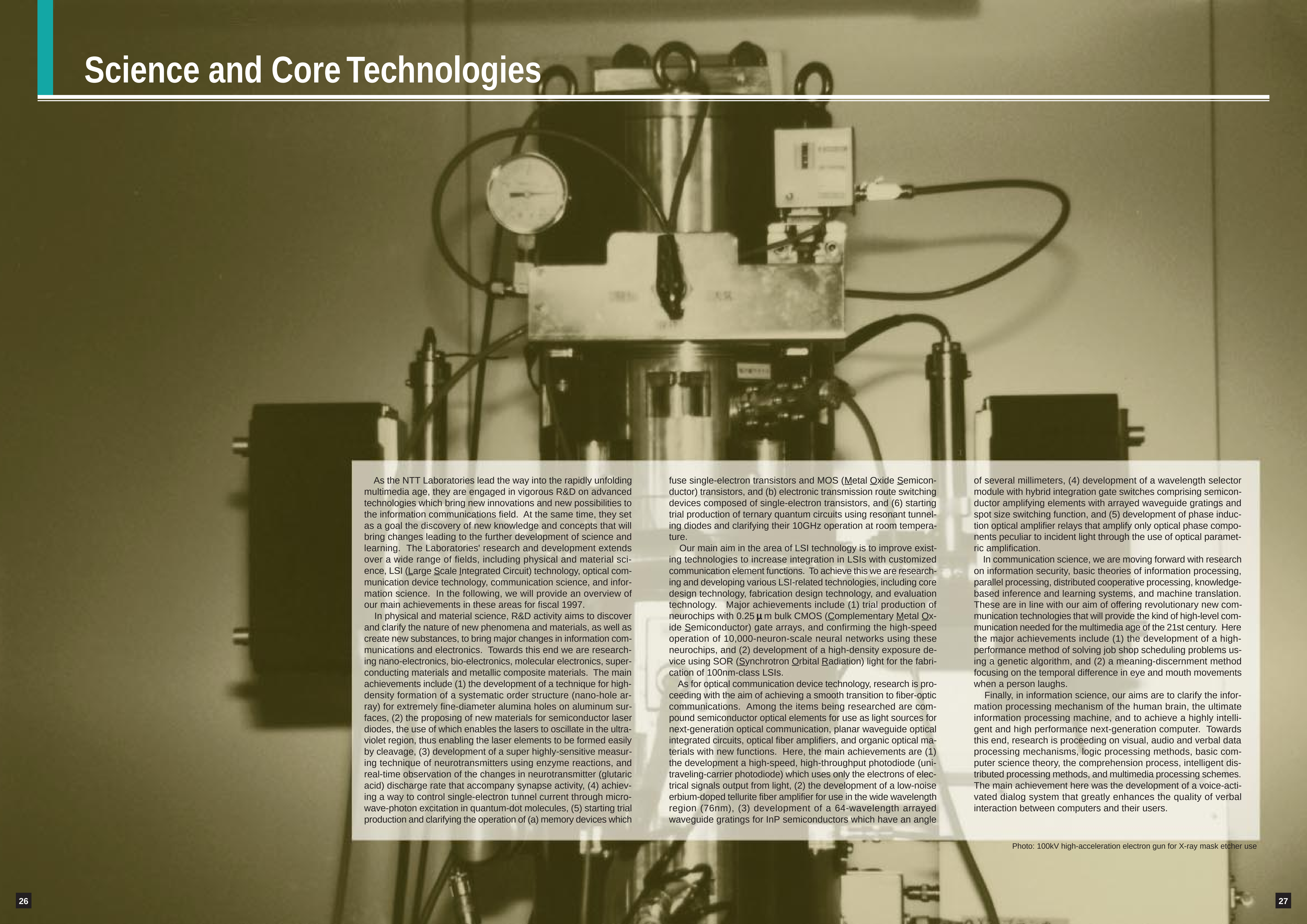
# Science and Core Technologies



As the NTT Laboratories lead the way into the rapidly unfolding multimedia age, they are engaged in vigorous R&D on advanced technologies which bring new innovations and new possibilities to the information communications field. At the same time, they set as a goal the discovery of new knowledge and concepts that will bring changes leading to the further development of science and learning. The Laboratories' research and development extends over a wide range of fields, including physical and material science, LSI (Large Scale Integrated Circuit) technology, optical communication device technology, communication science, and information science. In the following, we will provide an overview of our main achievements in these areas for fiscal 1997.

In physical and material science, R&D activity aims to discover and clarify the nature of new phenomena and materials, as well as create new substances, to bring major changes in information communications and electronics. Towards this end we are researching nano-electronics, bio-electronics, molecular electronics, superconducting materials and metallic composite materials. The main achievements include (1) the development of a technique for high-density formation of a systematic order structure (nano-hole array) for extremely fine-diameter alumina holes on aluminum surfaces, (2) the proposing of new materials for semiconductor laser diodes, the use of which enables the lasers to oscillate in the ultraviolet region, thus enabling the laser elements to be formed easily by cleavage, (3) development of a super highly-sensitive measuring technique of neurotransmitters using enzyme reactions, and real-time observation of the changes in neurotransmitter (glutaric acid) discharge rate that accompany synapse activity, (4) achieving a way to control single-electron tunnel current through micro-wave-photon excitation in quantum-dot molecules, (5) starting trial production and clarifying the operation of (a) memory devices which fuse single-electron transistors and MOS (Metal Oxide Semiconductor) transistors, and (b) electronic transmission route switching devices composed of single-electron transistors, and (6) starting trial production of ternary quantum circuits using resonant tunneling diodes and clarifying their 10GHz operation at room temperature.

Our main aim in the area of LSI technology is to improve existing technologies to increase integration in LSIs with customized communication element functions. To achieve this we are researching and developing various LSI-related technologies, including core design technology, fabrication design technology, and evaluation technology. Major achievements include (1) trial production of neurochips with 0.25 $\mu$m bulk CMOS (Complementary Metal Oxide Semiconductor) gate arrays, and confirming the high-speed operation of 10,000-neuron-scale neural networks using these neurochips, and (2) development of a high-density exposure device using SOR (Synchrotron Orbital Radiation) light for the fabrication of 100nm-class LSIs.

As for optical communication device technology, research is proceeding with the aim of achieving a smooth transition to fiber-optic communications. Among the items being researched are compound semiconductor optical elements for use as light sources for next-generation optical communication, planar waveguide optical integrated circuits, optical fiber amplifiers, and organic optical materials with new functions. Here, the main achievements are (1) the development a high-speed, high-throughput photodiode (uni-traveling-carrier photodiode) which uses only the electrons of electrical signals output from light, (2) the development of a low-noise erbium-doped tellurite fiber amplifier for use in the wide wavelength region (76nm), (3) development of a 64-wavelength arrayed waveguide gratings for InP semiconductors which have an angle of several millimeters, (4) development of a wavelength selector module with hybrid integration gate switches comprising semiconductor amplifying elements with arrayed waveguide gratings and spot size switching function, and (5) development of phase induction optical amplifier relays that amplify only optical phase components peculiar to incident light through the use of optical parametric amplification.

In communication science, we are moving forward with research on information security, basic theories of information processing, parallel processing, distributed cooperative processing, knowledge-based inference and learning systems, and machine translation. These are in line with our aim of offering revolutionary new communication technologies that will provide the kind of high-level communication needed for the multimedia age of the 21st century. Here the major achievements include (1) the development of a high-performance method of solving job shop scheduling problems using a genetic algorithm, and (2) a meaning-discernment method focusing on the temporal difference in eye and mouth movements when a person laughs.

Finally, in information science, our aims are to clarify the information processing mechanism of the human brain, the ultimate information processing machine, and to achieve a highly intelligent and high performance next-generation computer. Towards this end, research is proceeding on visual, audio and verbal data processing mechanisms, logic processing methods, basic computer science theory, the comprehension process, intelligent distributed processing methods, and multimedia processing schemes. The main achievement here was the development of a voice-activated dialog system that greatly enhances the quality of verbal interaction between computers and their users.

Photo: 100kV high-acceleration electron gun for X-ray mask etcher use

## Development of New Nano-Hole Materials Using Simple Nano-Fabrication Technology

High-density and ultra-fine nano-hole arrays in alumina manufactured by anodic oxidation of aluminium (Al) have been used for surface modification of Al or to make filters. However, conventional nano-hole arrays have poor regularity and periodicity, which limits the application of this material.

NTT Laboratories have developed a new simple technique for manufacturing highly regular nano-hole arrays in $Al_2O_3$ in collaboration with Associate Professor Hideki Masuda's group at Tokyo Metropolitan University.

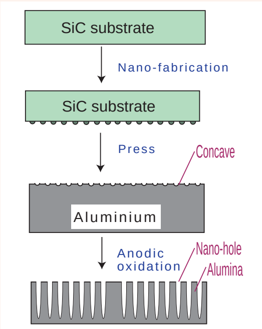
Noting that shallow fine concaves on the Al surface act as the stating point of anodic oxidation, we developed the new process shown in Figure 1. First, we fabricate an SiC mold with fine projection arrays by electron-beam exposure and dry-etching. Then, the Al substrate is pressed using this SiC mold to form fine concave arrays. Finally, the Al is anodically oxidized under an applied voltage suitable for the pitch of the arrays. This process allows us making highly regular nano-hole arrays with various pitches. Figure 2 shows microscopic pictures of 100-nm-pitch nano-hole arrays.

Our $Al_2O_3$ nano-hole arrays are characterized by extremely smooth side walls, and very high aspect ratio which can be more than 100, because the depth of the hole is simply proportional to the anodic oxidation time. Since these structural characteristics have been never observed in the conventional materials, our nano-hole arrays can be regarded as exciting new raw materials applicable to various uses.

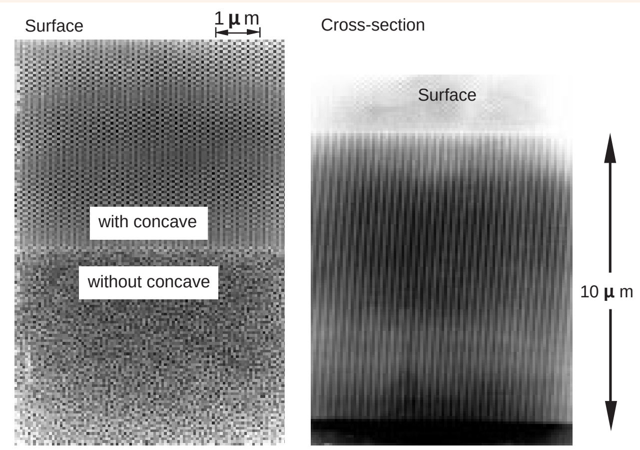
In close collaboration with Professor Masuda's group our laboratories will establish methods of manufacturing these new materials and will apply them to new optical components and environmental technologies in the near future.

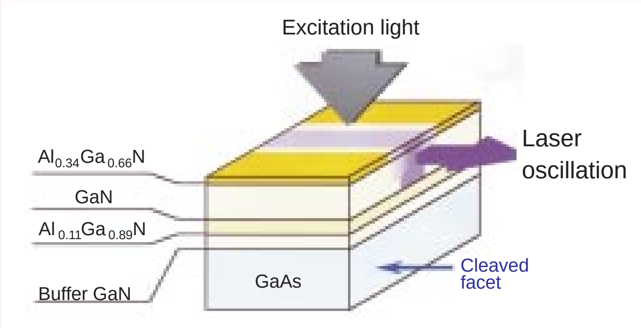
(Opto-electronics Laboratories)

Manufacturing process of nano-hole arrays

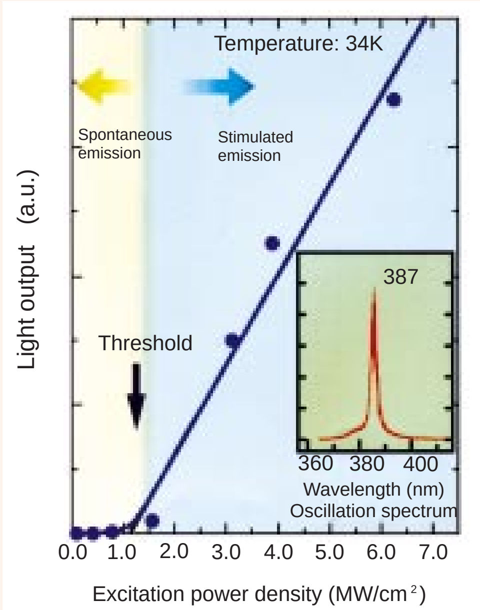



Electron micrograph of 100-nm-pitch nano-hole arrays




Device structure




Light output dependence on excitation power density

## New Material System for an Ultraviolet Laser Diode

The recording density of an optical storage system depends on the wavelength of the light source because the condensed spot size is limited by diffraction. Red laser diodes (wavelength: 650 nm) are currently used for DVD* systems, but laser diodes emitting in the region between blue and ultraviolet will allow higher-density video recording. Recently, blue or violet laser diodes have been developed using hexagonal group-III nitrides grown on sapphire substrates. Unfortunately, hexagonal group-III nitrides on sapphire are very difficult to cleave, which is a necessary process in the mass production of conventional laser diodes. We have proposed a double-heterostructure laser diode made from cubic group-III nitrides grown on GaAs substrates, because the cubic form is easier to cleave.

We grew cubic-AlGaN/GaN double-heterostructure crystal layers as shown schematically in the figure, and confirmed their lasing action. The laser cavity of the tested device was fabricated by conventional cleaving. We achieved lasing at a wavelength of 387 nm by optical pumping using a nitrogen laser. This wavelength is short enough to enable studio recording of video data with a low-cost storage system, such as a DVD system. Thus, this material system promises to make mass-produced inexpensive ultraviolet laser diodes practical.

(Integrated Information & Energy Systems Laboratories)

* DVD: Digital Versatile Disc

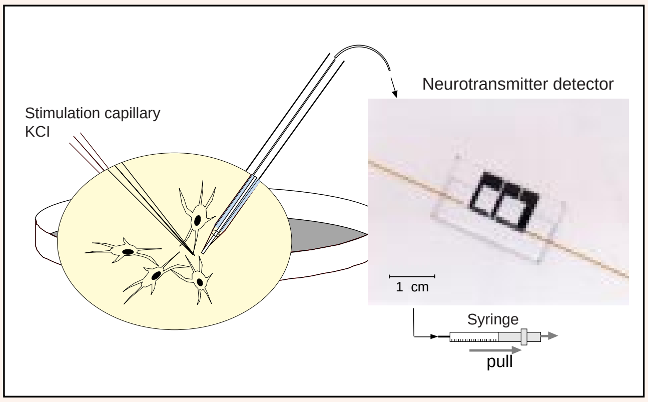
## Direct Observation of Neurotransmitters

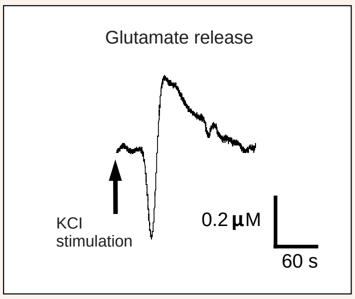
Human beings are capable of deciding on a course of action by analyzing vast amounts of information in a very short time and also of learning and memorizing various types of information. These functions are concentrated in the brain where hundreds of millions of neurons exchange information, mediated by various molecules called neurotransmitters. It could be said that these molecules enable us to realize things. These neurotransmitters are released into minute spaces called synaptic clefts which are a few tens to a few hundreds of nanometers in size. Although many efforts have been made to investigate their behavior, no method has worked successfully in real time and over a long period because their amount is so small.

We have developed a novel method for detecting glutamate, a very important neurotransmitter in the brain, by using a glutamate-specific enzyme reaction. The method employs a microcapillary and an enzyme-modified carbon electrode. This allows us to continuously measure glutamate concentration via electrochemical current responses. This means we can measure glutamate at the ppb level and investigate changes in its concentration. Furthermore, as shown in the figure, we have succeeded in reducing the size and volume of the detector and in improving the spatial and temporal resolutions (on the order of seconds and micrometers) tenfold compared with the previous detector, by using a micromachining technique. Although further improvement is required to measure the activity of a single synapse, we have been able to measure the change in glutamate concentration depending on synaptic activity for the first time. This method could prove to be a powerful tool for investigating synaptic efficacy, such as long term potentiation (LTP) and long term depression (LTD). We will continue our research, whose goal is to discover the mechanisms of information processing and memory function in the human brain.

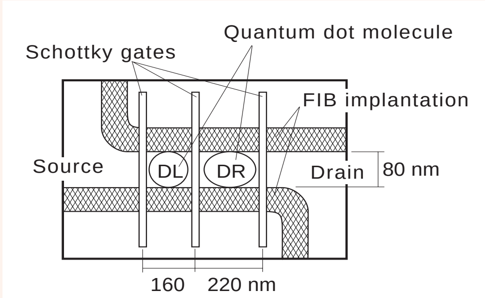
(Basic Research Laboratories)

Schematic diagram of glutamate measurement

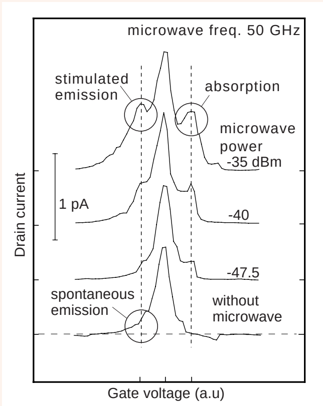



Real-time measurement of glutamate released from nerve cell




Schematic diagram of a quantum dot molecule




Gate voltage dependence of microwave-excited current

## Single Electron Tunneling Controlled by Microwave-Photon Excitation

Semiconductor quantum dots are often referred with artificial atoms since they show well-defined discrete electron states due to the zero-dimensional quantum confinement effect. When two of these quantum dots are formed close together, electron states similar to those in ionic or covalent molecules can be formed. These states can be investigated via the transport properties between electrodes weakly coupled to the dots. In collaboration with Delft University of Technology, we have observed bonding and anti-bonding states of quantum dot molecules using microwave-photon excitation spectroscopy, and have succeeded in controlling single electron tunneling by microwave-photon irradiation.

We fabricated a quantum dot molecule with a large bonding energy using focused ion beam (FIB) implantation and a split gate technique. A resonant photo-excited current was observed when the photon energy of the microwaves matched the energy separation of the molecular states. Single electron tunneling could be controlled by absorption or stimulated emission of one microwave-photon. The absorption and the emission depended on the gate voltages and the drain voltage. Furthermore, microwave spectroscopy successfully revealed the covalent molecular states of the quantum dot.

Single electron tunneling controlled by microwave photons is expected to lead to the development of novel quantum devices based on microwave-photon controlled quantum states or on the conversion of single-electron-tunneling to single-photon-generation.

(Basic Research Laboratories)

## Si Single-Electron Devices toward Integrated Circuits

Single-electron devices are expected to be a key device for a variety of electronic apparatus used in a future multimedia society because of their extremely low power consumption. We have developed a new reproducible method, named PADOX*[1], for fabricating Si single-electron devices, exploiting a special phenomenon that occurs when a Si nanostructure is thermally oxidized. Using this method, we have been investigating the integration of such devices to create higher functions. Two kinds of devices were fabricated and their fundamental operations were confirmed successfully. One is a double-throw switch that integrates three single-electron islands and the other is a memory device composed of a single-electron transistor and a MOSFET*[2].

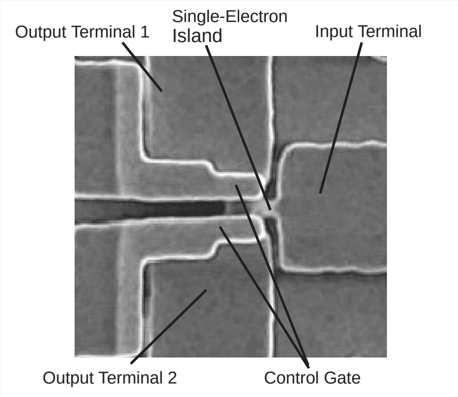
The double-throw switch device has an input terminal, two output terminals, and three control gates. The terminals are connected by a T-shaped Si layer which contains a small single-electron island in each of the branches. Input electrons are transferred to one of the output terminals selected by the voltage applied to the control gates. In the memory device, on the other hand, dozens of electrons are stored in a small island which is connected via a small MOS transistor to the electrode for writing and erasing. These electrons are detected by the single-electron transistor coupled capacitively with the island. Both devices can operate with an extremely small number of electrons, e.g., $10^{-5}$ to $10^{-3}$ times that of conventional electronic devices, which guarantees ultra-low-power operation.

(Basic Research Laboratories)

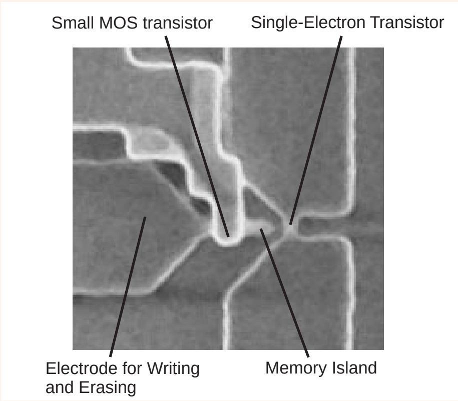
*[1] PADOX: Pattern Dependent Oxidation

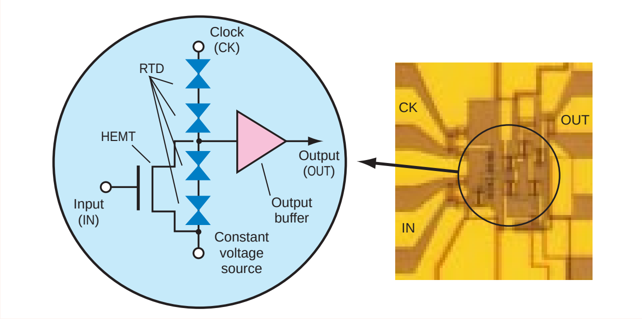
*[2] MOSFET: Meteal-Oxide-Semiconductor Field-Effect Transistor

Si single-electron double-throw switch combined with three single-electron island

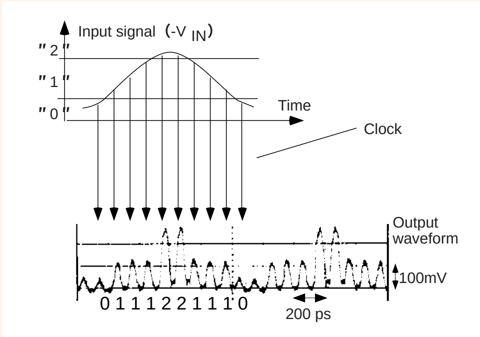



Si memory device composed of a single-electron transistor and a MOSFET




Ternary quantizer. Circuit configuration and chip micrograph




Output waveform quantized to three values at a clock rate of 10 GHz

## Ultrahigh-Speed Circuits Using Resonant Tunneling Devices

The demand for wireless communication terminals that can support high-speed and large-volume data transmission with low power consumption has been increasing in recent years along with the advancement of the multimedia information society. The development of high-performance electronic devices is essential for the construction of such wireless communication terminals. Although the performance of electronic devices has been improved through the reduction of device lateral size, further improvement has recently become increasingly difficult. Breaking through this performance ceiling will require the development of novel electronic devices.

Our laboratories have demonstrated that ultrahigh-speed circuits can be constructed with reduced complexity by using resonant tunneling diodes (RTDs) in combination with conventional high electron mobility transistors (HEMTs). RTDs are quantum effect devices, and feature ultrafast switching along with negative differential resistance characteristics (NDR). The NDR characteristics greatly simplify the configurations of various logic circuits. One of the developed high-speed circuits is a ternary quantizer, which converts an analog input signal to a three-valued quantized output signal. The core circuit of the ternary quantizer consists of only four RTDs and one HEMT. Ultrahigh-speed operation at clock speeds up to 10 GHz has been demonstrated for the fabricated ternary quantizer at room temperature. The circuits also feature low power consumption along with high-speed operation.

These results show that resonant tunneling devices are highly promising for making future ultrahigh-speed circuits. This multi-valued quantizer can be used as a key component for ultrahigh-speed analog-to-digital converters (ADCs). Given these results, our laboratories will pursue the development of ultrahigh-speed ADCs, which are key devices for future high-performance wireless communication terminals.

(System Electronics Laboratories)

## A Neurochip for Large-Scale Networks

An artificial neural network is a computational model whose design was motivated by the biological nervous system.  Since functions of neural networks are achieved by means of learning like in a human brain, they have strong potential for application to highly intelligent systems for pattern recognition, robot control, and nonlinear prediction.  A neural network is a network comprising many very simple processors, artificial neurons.  To solve real-world problems, we need huge networks of neurons and hours or days of computational time with a general-purpose computer like a workstation.

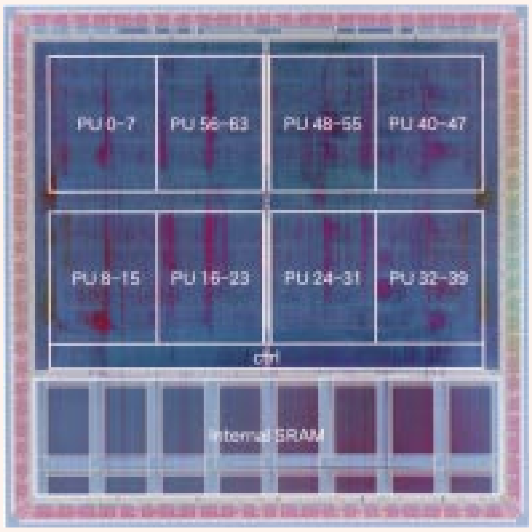
We have developed a neurochip, a dedicated LSI for neural networks, to achieve high-speed computation and a small chip size.  In conventional neurochips, as the parallelism of neuron computation increases, data paths from processing units to the external memory become a performance bottleneck.  We solved this problem by developing two novel techniques, compressible synapse weight neuron calculation (CSNC) and differential neuron operation (DNO).  These allow us to reduce the amount of computation and memory access to 1/100.

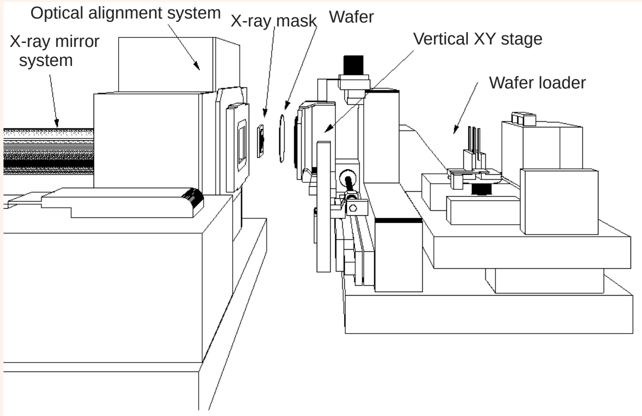
A prototype neurochip was fabricated using 0.25-µm CMOS technology.  It executes 10 GCPS* for forward calculations and can handle a 1-million synapse network together with external SRAM chips.  This neurochip allows a real-time processing neural network system to be constructed in the volume of a personal computer where as a conventional system currently needs a supercomputer.  Inexpensive, small neural network systems are expected to be applicable to many fields.

(Integrated Information & Energy Systems Laboratories)

* GCPS: Giga Connection Per Second

Micrograph of the neurochip fabricated using 0.25-µmCMOS technology



Configuration of the stepper


120-nm lines and spaces

## Development of an X-ray Stepper for Ultra-Fine Pattern Fabrications in LSIs with 100-nm Feature Size

The ongoing trend towards decreased feature size in LSIs is setting the stage for minimum feature sizes of 100 nm in 2005 and 70 nm in 2010.  Optical steppers utilizing ultraviolet light have recently been used for the fabrication of LSIs having a minimum feature size of around 250 nm.  However, optical steppers will be unsatisfactory for sub-150-nm pattern fabrication because of their resolution limit.  Therefore, it is necessary to develop a next-generation stepper.

NTT's laboratories have succeeded in developing an X-ray stepper that can fabricate ultra-fine 100-nm patterns.  To achieve this performance, we developed a perfectly friction-free vertical XY stage that carries out exact step-and-repeat movements, an optical heterodyne alignment system that detects displacement with high accuracy, a pin-chuck system that makes the wafer flat, an X-ray mirror system that delivers X-rays with relatively high efficiency, and software for controlling each component and the whole system.

This stepper overcomes the limits of conventional optical steppers, and is expected to contribute to the improvement of LSI technologies towards the 21st century.  We are going to improve this technology in collaboration with ASET (Association of Super Advanced Electronic Technologies, supported by NEDO).

(System Electronics Laboratories)

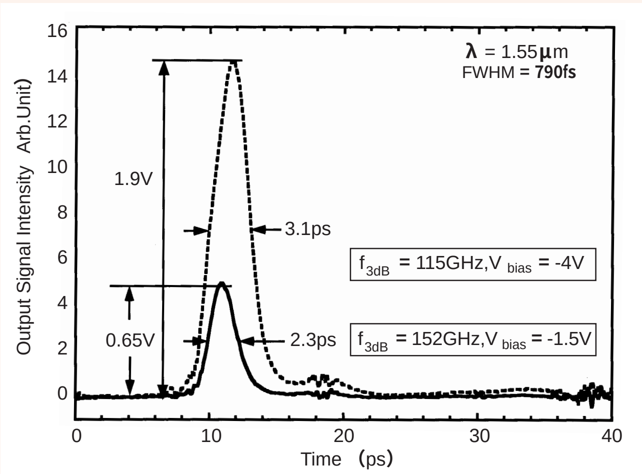
## Uni-Traveling-Carrier Photodiodes

Various semiconductor devices are being developed for future ultra-broadband fiber optic communication systems. One of the most important of these devices is a photodiode to receive optical signals. Recently, efforts concerning photodiodes have focused on increasing their output, because high output can eliminate the need for electronic post-amplification and improve photoreceiver characteristics.

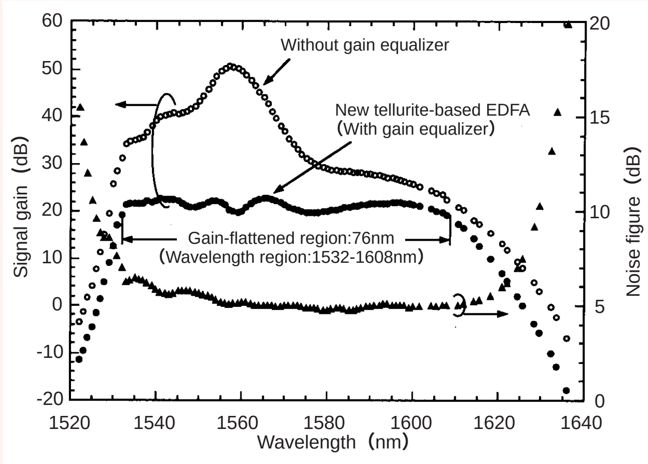
The key is a new operating mode using only electrons as active traveling carriers. Called a uni-traveling-carrier photodiode (UTC-PD), such a PD differs greatly from a conventional pin-PD, which uses both electrons and holes. Because the drift velocity of an electron is ten times that of a hole, the UTC-PD can operate with a faster photoresponse. The higher electron velocity also reduces the space charge accumulation effect, leading to a higher photocurrent and output. The fabricated planar InP/InGaAs UTC-PD yielded a -3 dB bandwidth of 152 GHz, which is the highest ever reported for a long-wavelength photodiode. The maximum output was as high as 3.5 V (for a 25-Ω load) which is about 20 dB higher than that of a conventional pin-PD. In order to improve quantum efficiency and facilitate advanced packaging, mesa-waveguide UTC-PDs have also been developed.

By making the best use of the high output of UTC-PDs, we have implemented a 40-Gbit/s photoreceiver without electronic amplifiers and a 40-Gbit/s optical modulator-based DEMUX module. UTC-PDs are also expected to be easily integrated with various electronic and photonic devices to generate new signal processing functions.

(System Electronics Laboratories, Opto-electronics Laboratories)




Photoresponse waveform of an InP/InGaAs uni-traveling-carrier photodiode (5-μm-diameter planar device, response for a 25-Ω load resistor)




Amplification characteristics of gain-flattened tellurite-based EDFA

## 1.5-μm Broadband Tellurite-Based Erbium-Doped Fiber Amplifier

1.5-μm-band optical wavelength division multiplexing (WDM) transmission and WDM optical network systems are very attractive because they make it possible to increase transmission capacity by exploiting the vast bandwidth of optical fiber, and will enable us to construct flexible networks that are transparent in terms of signal format and bit rate. In these systems, optical fiber amplifiers are the key components determining the system bandwidth. And there is now an increased need to develop an optical fiber amplifier for WDM signals which has a wide amplification band with uniform gain and low noise.

NTT researchers have proposed and developed a 1.5-μm broadband optical amplifier for WDM systems by employing tellurite-based erbium ($Er^{3+}$)-doped fiber (EDF) as the amplifying medium. This has an extremely wide amplification band of about 80 nm, which is more than twice that (30 nm) of conventional EDFAs. Moreover, as a result of focusing our efforts on flattening the gain spectrum and reducing the noise figure, we have now successfully developed a novel low-noise, gain-flattened, and broadband tellurite-based EDFA.

The key aspects of this development are: (1) fabrication of low-loss tellurite-based EDF (background loss ~ 0.05 dB/m at 1.2 μm) by using high-purity tellurium oxide ($TeO_2$), (2) reduction in the amplified spontaneous emission in the tellurite-based EDF by employing a cascade configuration, and (3) development of a gain equalizer in order to flatten the gain spectrum. As a result, we were able to achieve a 3-dB-down bandwidth of 76 nm in the 1532-1608 nm wavelength region with a signal gain of 22 dB, and a noise figure of less than 7 dB in the gain-flattened amplification region. Furthermore, we constructed a parallel-type amplifier composed of this tellurite-based EDFA and a newly developed 1.45-μm-band gain-flattened thulium ($Tm^{3+}$)-doped fluoride fiber amplifier. With it we achieved a total flat amplification bandwidth of 113 nm for the 1443-1484 nm and 1532-1608 nm signal wavelength regions.

We are continuing our efforts to expand the amplification bandwidth of this amplifier while improving its uniform gain characteristics and reducing the noise even further. In addition, we plan to undertake system tests with this amplifier to confirm its attractive amplification characteristics of uniform and broadband gain and low noise.

(Opto-electronics Laboratories)

## Semiconductor Photonic Devices Monolithically Integrated with Arrayed-Waveguide Gratings (AWGs)

Because it will be necessary to upgrade telecommunications networks to meet the increased traffic demands imposed by multimedia communications, photonic networks based on dense wavelength division multiplexing (DWDM) have been widely investigated, with the aim of establishing multimedia telecommunications networks with terabit-per-second capacity.

In WDM systems, one of the most important functions is wavelength multiplexing and demultiplexing, which combines and sorts different wavelengths. One of the best ways to realize this function is to use arrayed waveguide gratings (AWGs) in the wavelength multi/demultiplexers (MUX/DEMUX).

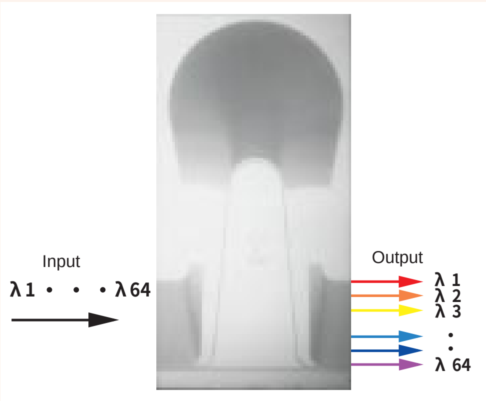
NTT Opto-electronics Laboratories have recently developed semiconductor-based 64-channel polarization-independent AWG MUX/DEMUXs. Since the refractive indexes of semiconductors are larger than that of silica glass, large-scale photonic circuits can be made in a very small area of only a few square millimeters.

Semiconductor photonic circuits are also advantageous for monolithic integration of active devices, such as laser diodes and photo-detectors, with AWGs. We have successfully fabricated an 8-channel demultiplexer with integrated photo-detectors for DWDM signal detection.

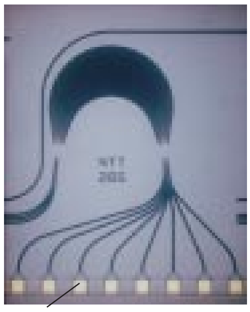
These devices will play an important role in monitoring and controlling DWDM optical signals in the future photonic networks.

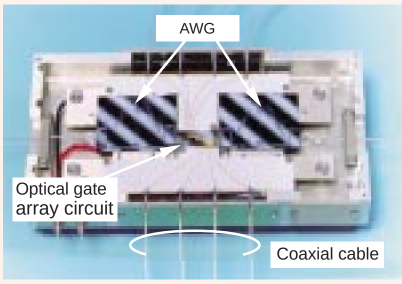
(Opto-electronics Laboratories)

64-channel semiconductor arrayed waveguide grating

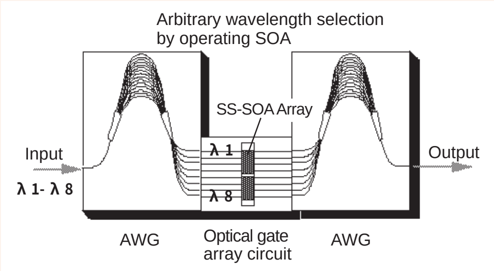



8-channel demultiplexer with integrated photo-detectors




Fabricated 8-channel optical wavelength selector module




Configuration of 8-channel optical wavelength selector module

## Hybrid Integrated 8-Channel Optical Wavelength Selector Module

As the multimedia era of the 21st century approaches, novel photonic networks based on optical wavelength division multiplexing (WDM) systems have been required in order to enlarge transmission capacities and improve network flexibility. In such networks, an optical wavelength selector is a key component which can pick out a signal of any arbitrary optical wavelength from multiplexed signals.

In the Opto-electronics Laboratories, an 8-channel optical wavelength selector module has been developed using hybrid integration of planar lightwave circuits (PLCs) and semiconductor devices. The selector consists of two arrayed waveguide grating (AWG) multi/demultiplexers and an optical gate array circuit with eight semiconductor optical amplifiers (SOA) integrated on a PLC platform. The input signals having different wavelengths are demultiplexed by the first AWG and fed to the SOA array. Each SOA in the array selects one of the signals and they are fed to the second AWG, which multiplexes the eight signals to the output port.

To make the wavelength selector, we developed 4-channel spot-size converter integrated SOAs, which can be integrated on a PLC platform without any lenses. Also, a PLC-PLC direct attachment technique has been introduced to connect two AWGs and the optical gate array circuit. Using these components, we made a wavelength selector that is compact and achieves a high switching speed. This hybrid integration technology based on a PLC platform can also be applied to various kinds of highly functional optical components.

Novel transmission systems based on the combination of the wavelength selector and other WDM components will be promising for future photonic networks.

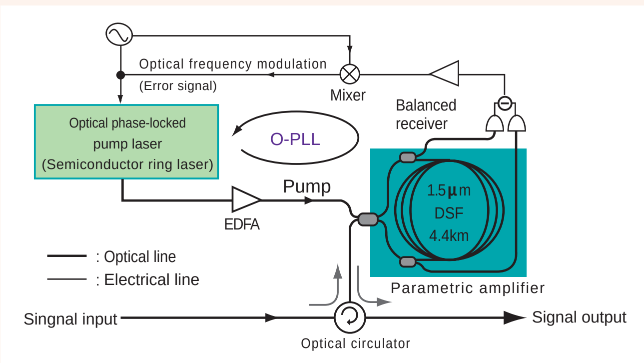
(Opto-electronics Laboratories)

## Optical Phase-Sensitive Amplifier Repeater

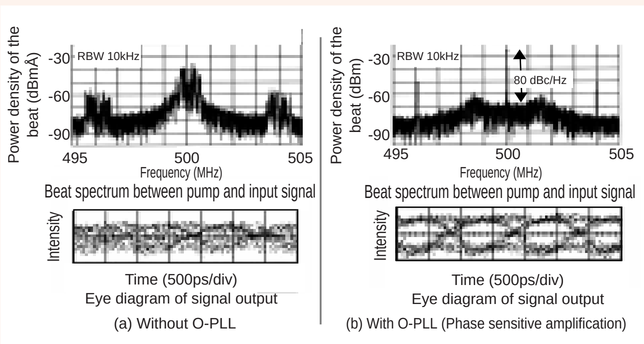
Current long-haul, high-capacity optical fiber transmission systems use erbium-doped fiber amplifiers (EDFAs) as linear repeaters. The transmission performance of such systems, such as repeater spacing and transmission capacity, is limited by the optical noise emitted by the EDFAs and the waveform distortion of optical signal pulses due to chromatic dispersion and nonlinearity in the transmission fiber. On the other hand, the phase-sensitive amplifier (PSA) is based on optical parametric amplification, unlike EDFA or semiconductor laser amplifiers which use simulated emission in the laser medium, and amplifies the optical signal component with long-term average optical-signal phase. It has been theoretically predicted that the PSA will offer an ultra-low noise figure and reshaping of distorted signal pulse waveforms. Thus a repeatered transmission system that use PSAs as repeaters should offer higher capacity and longer transmission distance.

However, the difficulties of preparing a pump light source for optical parametric amplification, whose optical phase should be locked to that of average the optical phase of input signal light, have prevented practical fabrication of PSA repeaters so far. We have made the first PSA repeater by using a new optical phase-locked pump laser source. The pump laser consists of a semiconductor laser with an external ring cavity and its phase is locked to the signal light by both an optical phase-lock loop (O-PLL) and optical injection locking. High in-phase gain is obtained by optimizing the chromatic dispersion of the fiber used in the nonlinear fiber Sagnac interferometer as a parametric amplifier. We plan to measure the transmission performance of a PSA repeated transmission system and establish a policy for designing PSA repeater systems.

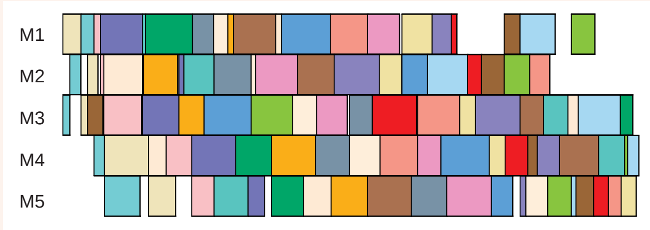
(Optical Network Systems Laboratories)



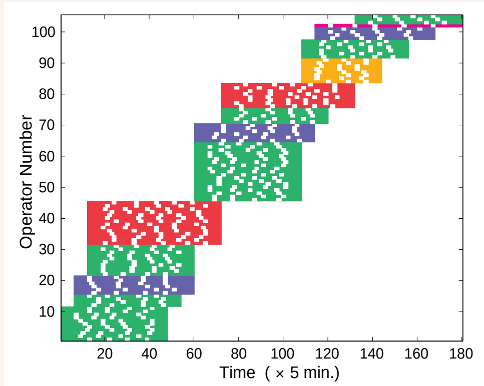

Configuration of PSA repeater using optical phase-lock loop (O-PLL)




PSA using optical phase-lock loop (O-PLL)




Optimal solution for the JSS problem MT20 × 5




Near optimal allocation of operators obtained by GA

## Optimal Scheduling by Genetic Algorithms

As societies and industrial fields become more complex, scheduling problems that allocate reusable resources so as to minimize time or cost are springing up, and there is a strong need for an efficient algorithm to solve them. Due to combinatorial explosion the existing exhaustive search methods can hardly solve any serious problems even if the fastest computers are used. Recently an approximate method using a genetic algorithm (GA) has attracted much attention. It is an abstract computational model of biological natural selection and heredity. Although strict optimality is not always guaranteed, GAs find excellent solutions even for large problems within a reasonable amount of time.

Using GAs we have investigated fast and high-quality schedulers for job shop scheduling (JSS) problems, the hardest scheduling problems. In JSS, the problem is to allocate shared machines to competing jobs through time under several constraints. We have developed a very powerful scheduler by employing both a genetic local search called multistep crossover and reversed order processing. Our scheduler can find the optimal or suboptimal solutions even for problems for which existing methods cannot find any good solutions.

Recently our optimal scheduling techniques have been applied to operators scheduling tasks of the CAST* system developed by NTT Communicationware Corporation, Shin-etsu regional division. The tasks require quickly finding a schedule that satisfies the working constraints of operators and at the same time minimizes the difference, shortage and surplus, from the predefined number of operators. By inventing new mutation methods and tailoring GA parameters, we could obtain a reasonably good solution within a few minutes using personal computers.

(Communication Science Laboratories)

* CAST: Communicator Allocation Support System

## Mechanism of Laughter —Quantitative Analysis by Dynamic Features of Facial Expressions

The purpose of our research is to clarify the mechanism behind human communication. Among various emotional expressions, laughter is the one most frequently seen in everyday life, and is an essential factor in facilitating smooth communication. Besides, laughter is used in various meanings, from social or psychological points of view. We have focused on laughter, and are investigating the mechanism of laughter by scientific means.

Part of our work looks at how people perceive various facial expressions of laughter. In our research, we have focused on the time lag between eye and mouth movements. Several computer-graphics animations of a smiling face were created, each differing only in the time lag between the starting points of eye and mouth movements. Subjects were asked to classify each animation into three categories of laughter: happy (laugh of joy), obligatory (forced laugh) or ironic (sneer or wry smile). After analyzing the responses, we found:

(1) when the mouth began moving before the eyes, smiles were taken as happy laughter

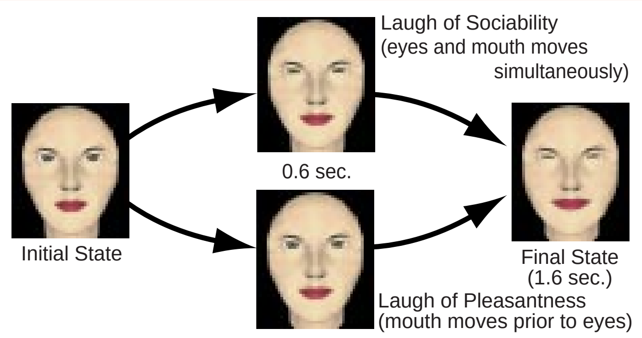
(2) when both movements began simultaneously, the laughter was considered forced,

(3) and when the eyes moved before the mouth, the laughter was considered ironic.

We are also studying the relationship between one's mental state and expression. We found the difference between two types of laughter: spontaneous laughter, caused by something funny, and forced laughter. We measured the surface EMG (electromyography) of facial muscles around the eyes and mouth, and the abdominal movements using a strain gauge. As a result, we found that the delay in abdominal reactions after facial reactions was significantly longer in forced laughter than in spontaneous laughter.

(Communication Science Laboratories)

Animation of smile




Spoken dialog system "Noddy"

## "Noddy" The Computer Who Nods

Speech communication is a promising medium for constructing an effortless human-machine information interchange system. This is not an unreachable dream. Recent advances in computing power have led to stochastic pattern recognition technologies that can achieve accurate and real-time speech recognition and make such a system possible.

Even if speech recognition reaches human-level accuracy, it will still be difficult to create a practical spoken dialog system. In addition to speech recognition accuracy, the total "effortlessness" factor should be discussed and implemented in real-world applications.

"Noddy", a spoken dialog system with an animated face, converses with human beings via speech. The humanoid face on the video display helps users to converse with the computer. In the idle state, its gaze wanders randomly. When a human voice is detected, the eyes are directed to the user. This gesture indicates that the system is aware of the user and ready to listen. When the system receives new information for performing target tasks via the user's utterances, the face nods and says "Yeah". Thus, this system expresses its internal status by facial actions such as wandering or focused gaze and nodding. The "Noddy" technology enables an effortless and barrier-free human-machine interface based on daily speech communication.

(Basic Research Laboratories)