Contents

H-CT-1 10-Gbit/s APD-ROSA Module
H-CT-2 Optoelectronic High-speed Bidirectional Serial-parallel Converter (OCTA)
H-CT-3 Future Phone: t-Room
H-CT-4 High-precision Control of Nuclear Spins for Quantum Computation
H-CT-5 All-optical Switch Based on Photonic Crystal Ultra-small Nanocavities
10-Gbit/s APD-ROSA Module

In recent years, traffic on communications networks has increased drastically due to the rapid spread of Internet and cellular phone use. This situation demands faster and higher-capacity communications systems, and 10-Gbit/s-class optical communications systems have been introduced as commercial systems. One way to reduce the cost of core and metro network systems is to extend the transmission distance between nodes.

The optical receiver module is a key component in such systems. The pin photodiode is widely used for the receiver. Replacing the pin photodiode with an APD*1, in which the device itself has an amplification function, may increase receiver sensitivity and make it possible to extend the transmission distance without using optical amplifiers. That would have a large impact on reducing network cost.

NTT Laboratories have developed an APD with a new device structure that realizes higher reliability and higher yield. For this APD, we have also developed a compact and low-cost module called ROSA*2, which is assembled with a transimpedance amplifier. This module is based on the industry standard specifications called XMD-MSA*3. It has an LC receptacle for the optical interface and a flexible printed circuit for the electrical interface. Error-free operation with a minimum receiver sensitivity of -27.0 dBm is demonstrated for a 1.55 µm NRZ*4 optical signal at a transmission rate of 10.7 Gbit/s, indicating that this module is fully applicable to a 10-Gbit/s optical communication system.

The 10-Gbit/s APD-ROSA modules will be commercially available from the NTT Group company in 2006.

*1 APD: Avalanche Photodiode
*2 ROSA: Receiver Optical Sub-Assembly
*3 XMD-MSA: 10-Gbit/s Miniature Device-Multi Source Agreement
*4 NRZ: Non Return to Zero

Photograph of 10-Gbit/s APD-ROSA module
Optoelectronic High-speed Bidirectional Serial-parallel Converter (OCTA)

NTT Photonics Laboratories

Future optical packet-switched routers will require the ability to recognize and exchange/swap the labels of high-speed asynchronous optical packets. In previous work, we achieved this label processing by developing a serial-to-parallel (SP) and parallel-to-serial (PS) converter as interfaces between the input/output optical labels and CMOS*1 electronics. Considering the large number of optical label processors required at each router, further reduction of size and power is necessary. As a solution, we propose and demonstrate a novel optically clocked transistor array (OCTA) with bidirectional SP/PS conversion capability.

The label of the input optical packet is separated from the payload*2 and fed into a PD*3 and Optical Clock-Pulse Generator. The PD converts the input label to an electrical signal and the Optical Clock-Pulse Generator produces a single optical clock pulse synchronized with the input packet. The OCTA employs this clock pulse as a trigger to convert the high-speed serial electrical label signal into slow parallel signals which are written into CMOS circuits (SP conversion). CMOS circuits extract the address information from the label and determine the output label. This new label is output in parallel from the CMOS circuits into the OCTA, with optical triggering generating the label as a serial voltage signal (PS conversion). An optical modulator converts the electrical label to an optical signal, which is coupled to the payload to complete the label swapping process. We have experimentally demonstrated bidirectional SP/PS conversion of 40-Gbit/s, 8-bit labels.

The proposed OCTA creates, with a single chip, an interface between high-speed asynchronous signals and CMOS circuits, to enable a low cost, low power, compact optical label processor. Future plans include fabrication of a label processor module and its application to an optical packet-switched router.

*1 CMOS: Complementary Metal Oxide Semiconductor
*2 payload: The section of the packet which excludes the label (i.e., attached information such as the address) and contains the actual data to be transmitted.
*3 PD: Photodetector

Label swapping principle of operation and OCTA chip
Future Phone : t-Room

Even with the availability of video conferencing systems, there still seem to be occasions where there is no substitute for direct face-to-face discussions. Conventional video conferencing systems have aimed to create a strong feeling of presence by employing high-quality audio and video and virtual reality technology. However, conventional systems do not fully recreate the interactions that naturally take place between people who are gathered in the same room.

For example, if person A sees person B from a diagonal perspective, then person B should see person A from a diagonal perspective. The apparent distance of person A from person B should also match the apparent distance of person B from person A. If person A moves, then the apparent direction and distance of person A from person B should change, and vice versa. Their positional relationship should also be immediately apparent to a third person C who is viewing them from the side. These things that people take for granted when they are all in the same room are not conveyed by conventional video conferencing systems. At NTT Laboratories, we have developed a video conferencing system called “t-Room” that creates the feeling of being in the same room as users who are separated spatially and even temporally.

We demonstrated this system at the NTT Communication Science Laboratories Open House 2005 back in June, and many visitors were highly impressed by the feeling of being in the same room. In December we launched the official “t-Room” website at (www.mirainodenwa.com). This site is packed with all sorts of information, including a description of the technology behind “t-Room” and an 11-minute demonstration video. To convey a feeling of being in the same room when people are present at different times, “t-Room” allows an earlier conference to be recorded and played back during a later conference. This later conference can itself be recorded and played back during another conference in the future. This playback feature plays a role similar to that of quoted text in emails. You are invited to take a look at the demonstration video.

At NTT Laboratories, we are considering “t-Room” as a future form of telephone service. Based on this technology, it will be possible to provide a wide variety of communication services, establish connections even to mobile phones and PCs, and allow people to communicate with each other. There are endless possibilities for this technology.

The “t-Room” configuration and layout of the demonstration system

![Diagram of the hardware configuration of “t-Room”]

![Diagram of the arrangement of displays, cameras, speakers and microphones]

![Demonstrating the system]
High-precision Control of Nuclear Spins for Quantum Computation

If the possibilities of quantum mechanics were to be fully exploited, it would be possible to make something unprecedented: a quantum-mechanical bit (qubit), which is neither zero nor one but instead a random superposition of zero and one. A quantum computer could be built from the successful integration of many qubits. Research into quantum computers is still in the very early stages, and the biggest challenge is currently how to produce ideal qubits. Nuclear spin is in the spotlight, as it maintains quantum-mechanical properties for a long time without being influenced by its surroundings. The big issue is how to control nuclear spins in solid-state systems.

NTT Laboratories have verified that strong interactions between electrons and nuclear spins may be produced under certain conditions when electrons enclosed in a thin film of high quality semiconductor produce a special situation called the fractional quantum hall effect. This phenomenon has been successfully applied to precision control of nuclear spins in a nanoscale semiconductor device. The compactly integrated structure has opened the way for nuclear spin control with unprecedented precision. The quantum-mechanical superposition between four separated states peculiar to the nuclei of gallium (Ga) and arsenic (As) can be fully controlled in our device.

The successful control of nuclear spin with a nanoscale device, which is notably an all-electrical control, is a significant step forward towards scalable nuclear spin quantum computers. This technology is also attractive as a nanoscale nuclear magnetic resonance (NMR) technology using an extremely small volume of material.

Coherent control of nuclear spins in a nanometer-scale semiconductor device

The semiconductor chip used in the experiment, schematic diagram of the nano-device incorporated inside, and color plot of the variation in the resistance of the nano-device measured near the NMR resonance frequency of As. Various quantum-mechanic transitions between four states, which are typical of As, are controlled with high precision, and clear oscillation is observed.
All-optical Switch Based on Photonic Crystal Ultra-small Nanocavities

Photonic technologies, such as NTT’s B FLET’S service, are being employed in all kinds of networks, and they enable today’s high-speed and wide-band information society. However, photonics is known to have certain disadvantages in comparison with electronics, such as larger device size and higher energy consumption for signal processing. With the aim of overcoming these fundamental problems, NTT Laboratories have been investigating photonic crystals, which are artificial structures created with nano-fabrication technologies. Photonic crystals have periodically modulated refractive indices that strongly confine light and enhance light-matter interactions.

It has been predicted that photonic crystals can be used to make ultra-small optical resonators that cannot be made with other existing technologies, and such tiny resonators would enable tremendous reductions in the energy consumption of various optical devices. NTT Laboratories have created the world’s first all-optical switch, which consists of ultra-small optical resonators and waveguides in a silicon photonic crystal chip. This switch is based on an ultra-small optical resonator having two resonant modes, and light is confined in a volume as small as 0.1 cubic µm. Two modes are used for the signal and control lights, and switching is accomplished by shifting the resonant wavelength of the signal light by inputting the control light. The switching speed is approximately 100 ps\(^1\), and the switching energy is as small as 100 fJ\(^2\), which is the smallest value ever reported for silicon optical switches. This device operates as a bistable switch, which can be employed for various logic functions, and a large number of similar switches can be integrated within a small chip. These characteristics hold out the possibility of creating one-chip all-optical logic circuits, a feat which has long been considered impossible. This accomplishment is largely based on highly accurate ultra-fine photonic-crystal fabrication technologies cultivated at NTT Laboratories. Recently, photonic-crystal waveguides and resonators developed by NTT and using the same fabrication technologies recorded the world’s lowest propagation loss and highest quality factor, respectively.

As its next target, NTT aims to develop a form of integration of similar all-optical switching devices. The energy consumption and operating speed of these switches will also be improved.

\(\text{*1 ps: } 1/10^{12} \text{ seconds} \quad \text{*2 fJ: } 1/10^{15} \text{ joule}\)

B FLET’S is a registered trademark of Nippon Telegraph and Telephone East Corporation and Nippon Telegraph and Telephone West Corporation.

**Structural description and operation of all-optical switches based on photonic-crystal ultra-small cavities**