Innovative Photon-Controlling Devices Based on Artificial Optical Properties of Semiconductors
- Exploration towards Digital Photonics -

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Abstract

This project is aiming at drastic improvements in optical active functions such as light emission, amplification, and detection as well as in optical nonlinearity through innovation of optical properties of semiconductors by utilizing artificial crystal structures designed and fabricated with mono-atomic order preciseness. It is also targeting evolution of optical communication technologies by establishing fundamentals of digital photonics, or more specifically, by realizing optically-controlled digital photonic devices and circuits based on the artificial optical properties of semiconductors, including optical dynamic memories, optical logic devices, digital wavelength converters, and optical 3R repeaters.

I. Introduction

Optical communication system technologies are advancing very rapidly, that include dense wavelength division multiplexing (DWDM), high speed optical time division multiplexing (OTDM), optical packet switching, microwave/photonic access link, and photonic internetworking. Although the optoelectronic technologies have been driven by materials and devices research conventionally, the bottle neck at present seems to exist in optical devices. A part of the reasons may be attributed to the fact that the conventional optical devices have been analog devices; the amplification has been possible but the regeneration (resetting signal to noise ratio) has not been possible. In addition no optical memory device has been available besides the fiber delay line. Consequently, sophisticated processing of optical signals has never been possible. What is requested for the next generation is "digital photonic device" where there is highly nonlinear all-optical response function as shown in Fig. 1, as well as "optical memory device" that is flexible like the present electronic memories.

More specifically, digital functions that are necessary for all-optical networking are •high speed optical buffer memory, •high speed optical logic gate, •high speed optical 3R (reshaping, retiming, regeneration) function, and •digital wavelength conversion. In order to realize them, one needs very high optical nonlinearity with low optical power. In this particular project, we are looking at carrier-associated optical nonlinearity in semiconductors which is substantial from low optical power and is fast enough if the material is properly designed.

The approach this project takes is following:

- In semiconductors, it is possible to fabricate artificial crystals which are designed and controlled to single atomic layer preciseness.
- Then, utilizing the artificial crystals, control of electron wave functions is made possible.

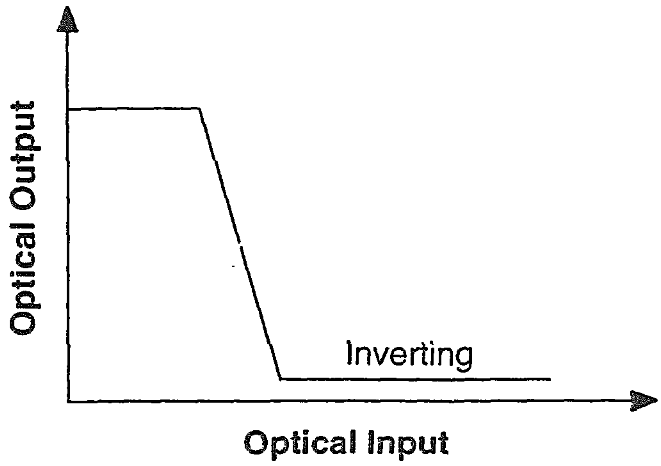

Fig. 1. Ideal transfer functions of all-optical digital devices.

- As a result, alteration of macroscopic optical properties can be done by the microscopic electron wave function control.
- This should lead to large artificial optical nonlinearity necessary for digital photonic devices.

Once large optical nonlinearity is prepared, the digital photonic devices and circuits would be realized by combining it with optical resonators. This is analogous to electronic circuits where functional circuits are formed by the combination of transistors and LCR components.

The unified purpose of research in this project is, therefore, to innovate fundamental optical active functions and optical nonlinearity in semiconductors by engineering crystal structure atomic layer by atomic layer, and to realize, based on the innovated optical properties of materials, all-optical digital devices and circuits such as optical dynamic memories, optical logic devices, digital wavelength converters, and optical 3R repeaters, thus establishing fundamentals of the "digital photonics."

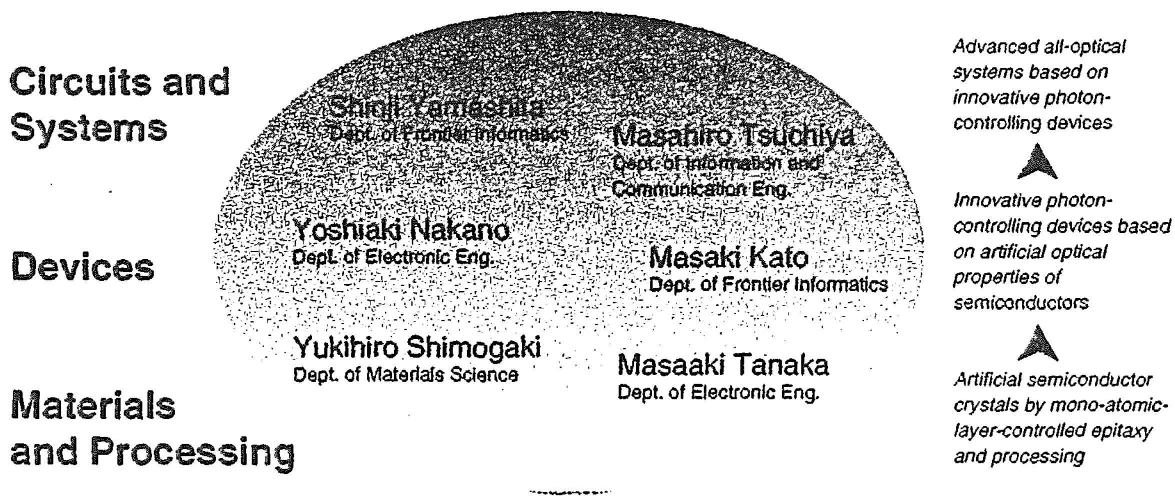

Fig. 2. Organization of the research team.

2. Organization

The organization of the research team for this project is depicted in Fig. 2. The materials and processing part of the project is mainly looked after by M. Tanaka and Y. Shimogaki whereas the device part is investigated largely by Y. Nakano and M. Kato. The system part of the project is researched by M. Tsuchiya and S. Yamashita.

3. Research Plan

Figure 3 shows the planned schedule of research over the five year period of the project. In accomplishing the purpose of the project, it is imperative to have epitaxy technology with atomic order accuracy (in particular, the interface abruptness is essential), sub micron delineation and etching techniques, and simulation technology to bridge the macroscopic optical properties and electron wave functions. Another emphasis is placed on the arrow in the figure which means continuous effort to transfer the fruits of research to the next higher level. This is important for having every researcher in the project focus on the unified purpose described in the previous chapter.

4. Current Research Status

As illustrated in Fig. 3, there are a number of research subjects going concurrently. In this particular symposium, we will pick up some subjects out of all and report the results more or less in detail on the following pages and in the poster presentations.

The activities that the author himself will introduce are:

- Asymmetric triple coupled quantum well (ATCQW) for low voltage digital optical switching (Fig. 4),

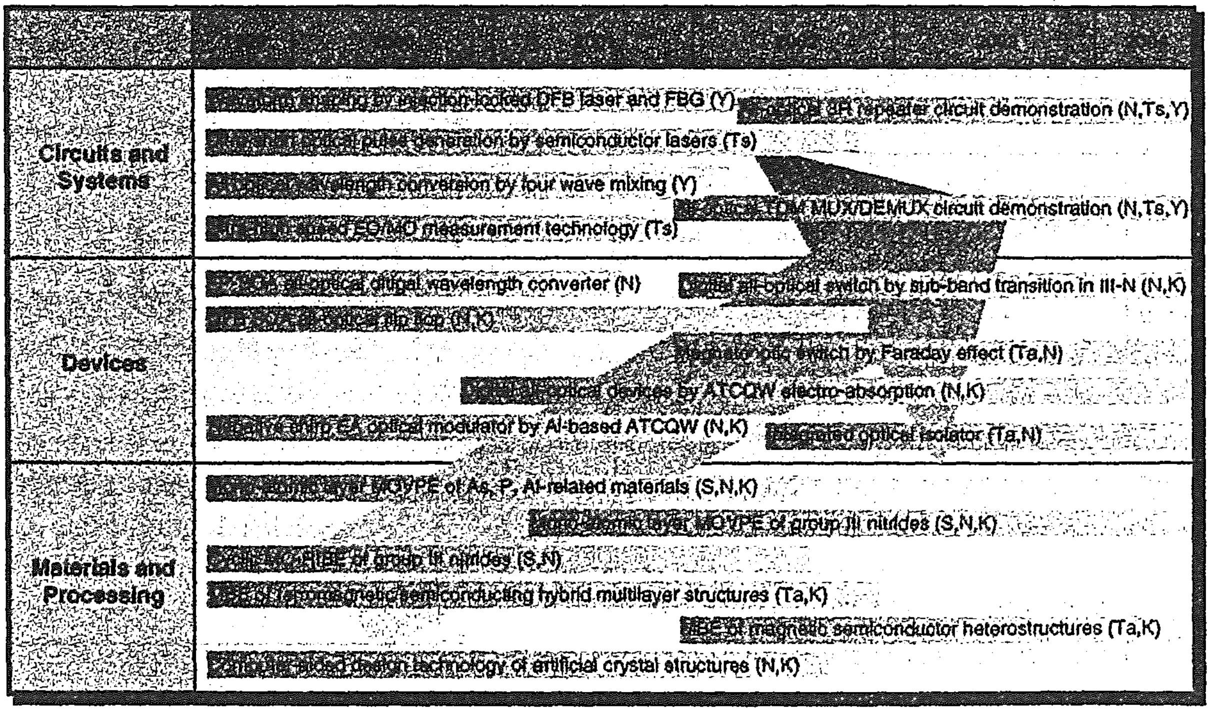

Fig. 3. Schedule of research and development over the period of the project.
(N: Nakano, S: Shimogaki, Ta: Tanaka, K: Kato, Ts: Tsuchiya, Y: Yamashita)

- All-optical digital wavelength conversion based on directionally-coupled semiconductor optical amplifiers (SOAs) (Fig. 5),
- All-optical digital wavelength conversion based on Fabry-Perot (FP) SOAs (Fig. 6), and
- All-optical flip flop based on distributed feedback (DFB) SOAs (Fig. 7).

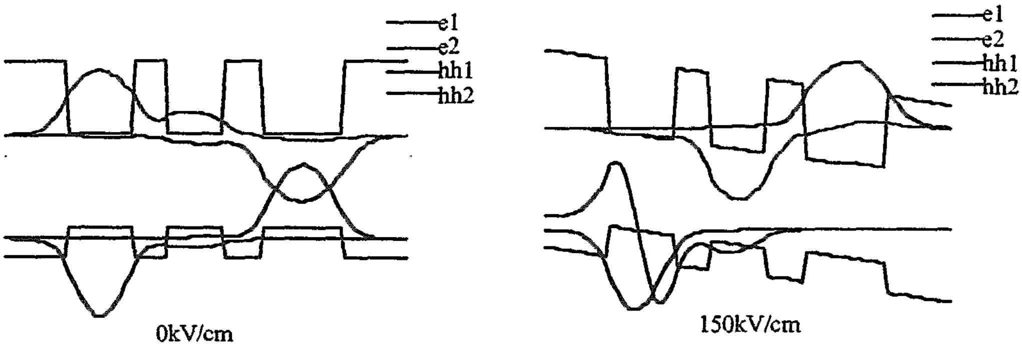

Fig. 4. Band structure of the asymmetric triple coupled quantum well (ATCQW).

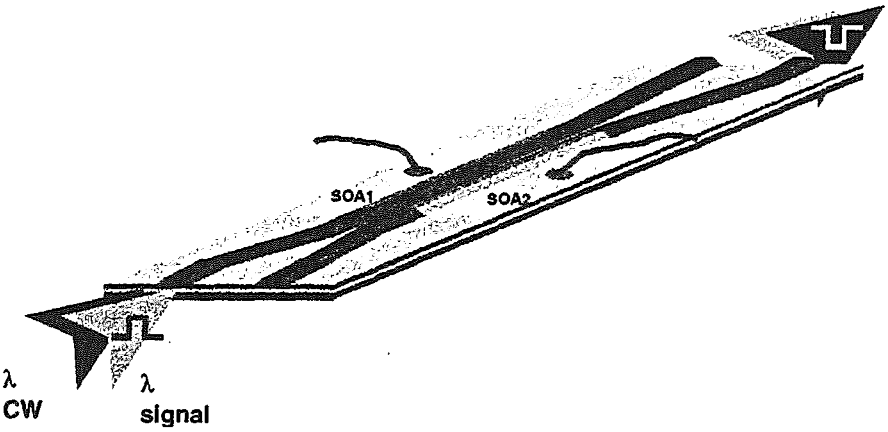

Fig. 5. Schematic of the directionally-coupled semiconductor optical amplifiers.

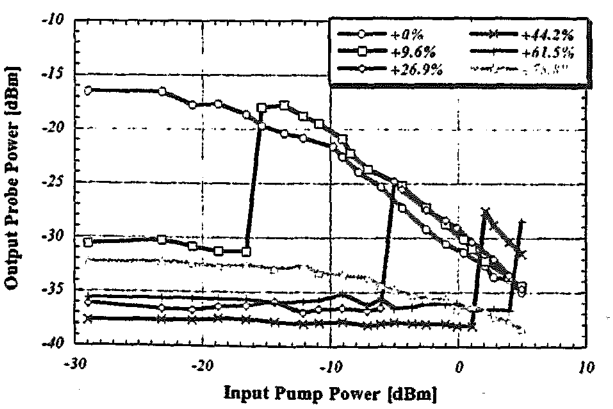

Fig. 6. All optical wavelength conversion characteristics in a Fabry-Perot SOA.

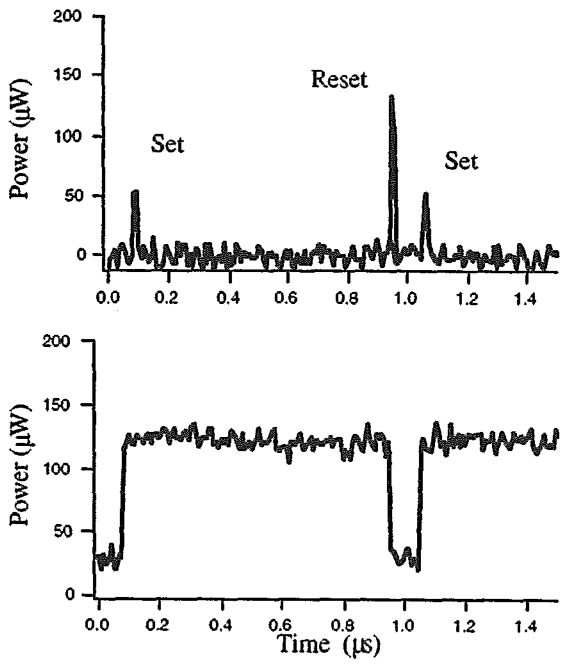

Fig. 7. All optical flip flop operation in a distributed feedback SOA.