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A Novel Optical Self-Routing Switch with a Wavelength Filtering Function Using a Vertical to Surface Transmission Electro-Photonic Device

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We report the first demonstration of an optical self-routing switch with a wavelength filtering function. This switch uses laser mode vertical to surface transmission electro-photonic (VSTEP) devices. The light input signal, which illuminates the VSTEPs, consists of a pilot signal and data signals. The pilot signal controls the ON/OFF state of the VSTEPs and seeks an output port for the data signal. The data signal which has a resonance wavelength in the VSTEP cavity is selectively transmitted through the VSTEPs during the ON state but is not transmitted during the OFF state.

1. Introduction

Optical interconnections have an advantage over electronic interconnections because they are free from mutual interference and capacitive charging requirements. The scope of optical interconnection applications is enlarged by optical functional interconnections, which can achieve high level optical processing such as photonic switching.

In order to realize optical functional interconnections, various vertical to surface transmission electro-photonic (VSTEP) devices[1),2)] have been developed. As an example of optical functional interconnections, a self-routing network[3)] has been proposed. An electrically variable self-routing switch[4)] and an optical multiplier/adder[5)] have also already been demonstrated by using VSTEPs. Here, we demonstrate the first optical self-routing switch with a wavelength filtering function by using laser mode VSTEPs. In this optical self-routing switch, the light input itself can determine the output port.

2. Device Structures

The device structure is shown in Fig.1. The epilayers were grown on an n-GaAs substrate by molecular beam epitaxy. They are as follows: an n-GaAs buffer layer (0.5μm, $2\times10^{18}cm^{-3}$), an n-$Al_{0.4}Ga_{0.6}As$ cathode layer (1μm, $2\times10^{18}cm^{-3}$), a p-$Al_{0.25}Ga_{0.75}As$ charge sheet layer (50Å, $1\times10^{19}cm^{-3}$), an undoped GaAs active layer (0.1μm) sandwiched between two $Al_{0.25}Ga_{0.75}As$ guiding layers (0.3μm and 0.1μm), an n-$Al_{0.25}Ga_{0.75}As$ n-gate layer (0.5μm, $1\times10^{17}cm^{-3}$), a p-$Al_{0.4}Ga_{0.6}As$ anode layer (1μm, $2\times10^{18}cm^{-3}$), and a p-GaAs cap layer (0.5μm, $1\times10^{19}cm^{-3}$). The undoped layers were p type and the background carrier concentrations were $1\times10^{15}cm^{-3}$.

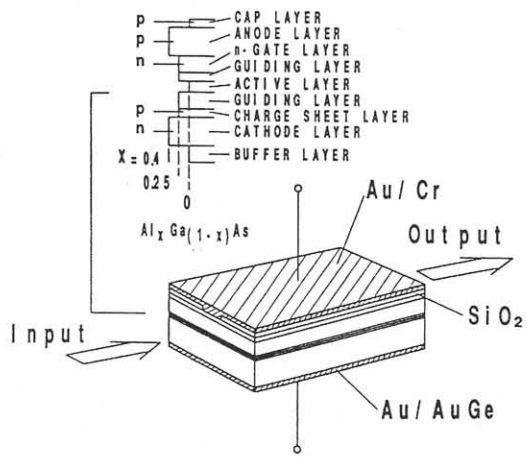

Fig. 1 Device structure for a laser mode VSTEP.

The cavity length was 275μm and both facets were cleaved and the facet reflectivity was 32%. This device emitted a laser light which had a wavelength of 880nm. While the device shown in Fig. 1 has light input and light output parallel to the active layer, vertical light transmission could be achieved by forming 45 degree mirrors at both ends for internal light reflection.[2)]

Fig. 2 shows the current-voltage characteristics and the current-light output characteristics for a VSTEP. The threshold current is 120mA and the external differential quantum efficiency is 40% per facet. The switching voltage Vs is 11.2V, and the holding voltage is 1.6V.

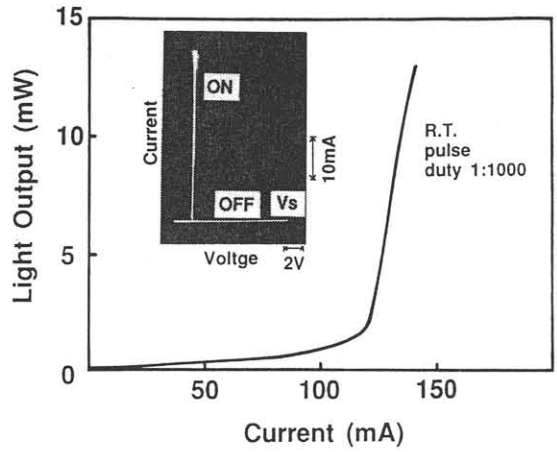

Fig.2 Current-Voltage characteristics and Current-Light output characteristics.

3. Principle of operations

Fig. 3 shows the principle of operations for the optical self-routing switch with a wavelength filtering function. In this switch, light input signals consist of an optical pilot signal and optical data signals. The optical pilot signal, which determines the destination for the optical data signals, is placed in front of the optical data signals. For electric signals, a control signal is followed by bias voltage. The sequence of the electric control signal and bias voltage is fixed. The voltage of the control signal is set higher than the bias voltage so that only the pilot signal, which is synchronized with the control signal, may switch on the VSTEPs. In Fig. 3, VSTEP1, in which the pilot signal synchronizes with the electric control signal, is selectively switched on. During the ON state, VSTEP1 is biased below the threshold current by adjusting the bias voltage and the resistance connected to VSTEP1. As a result, VSTEP1 functions as an optical amplifier and the data signals are transmitted through only VSTEP1 once it is switched on. On the contrary, VSTEP2, in which the pilot signal does not synchronize with the control signal, remains in the OFF state and the

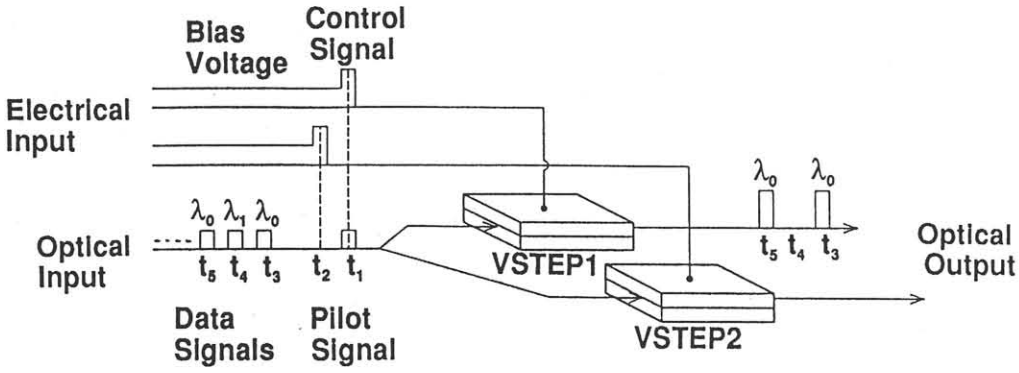

Fig.3 Principles of operations for an optical self-routing switch with a wavelength filtering function. In this switch, a VSTEP1 is switched on by an optical pilot signal which synchronizes with an electric control signal. Data signals which have a resonant wavelength λ_0 are selectively transmitted through VSTEP1.

data signals are not transmitted, because it is absorbed. When both facets of the VSTEPs have reflectivity, the VSTEPs selectively amplify the light input whose wavelength fits the resonance wavelength in the cavity during the ON state. The resonance wavelength depends on the effective refractive index of the VSTEPs. Since the effective refractive index is tuned by the injection current due to free carrier plasma effect, the resonance wavelength can be tuned by the injection current. This means that bias voltage can control the resonance wavelength.

In the scheme shown in Fig. 3, it is necessary to generate the electric control signal which synchronizes with the optical pilot signal. Also, an electric reset pulse is required to switch off the VSTEPs. One method to generate the electric signals is as follows: An optical set flag is added in front of the pilot signal and an optical reset flag is placed after the data signals. A detector detects the optical set flag and an electric circuit generates the electric control signal and bias voltage. Similarly, when the optical reset flag is detected, an electric reset pulse is applied to the VSTEPs.

4. Experiment

The experimental set up was as follows: The optical pilot signal and the optical data signals were coupled into two VSTEPs with hemi-spherical-ended single mode optical fibers. Coupling loss was 6dB per facet. The VSTEP was also used as a light source.

Fig. 4 shows the optical switching energy dependence on bias voltage. An increase in bias voltage results in a decrease in the optical switching energy, which was 6.4pJ at 0.83Vs.

Fig.5 shows the light output spectra for the data signals during the ON state at (a) a resonant wavelength and (b) an off-resonant wavelength. A

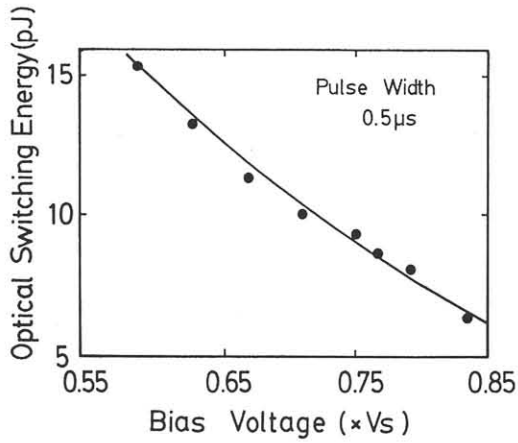

Fig. 4 Optical switching energy dependence on bias voltage.

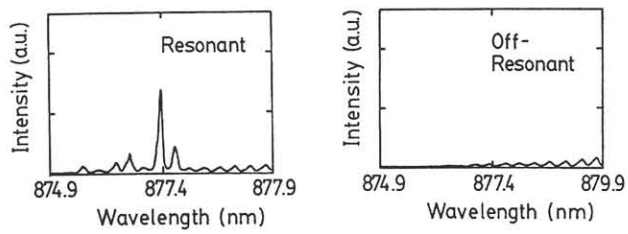

Fig. 5 Light output spectra for data signals at (a) a resonant wavelength and (b) an off-resonant wavelength.

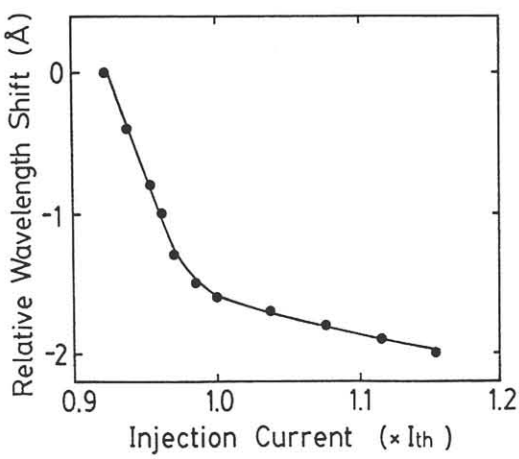

Fig. 6 A resonance wavelength shift as a function of the injection current.

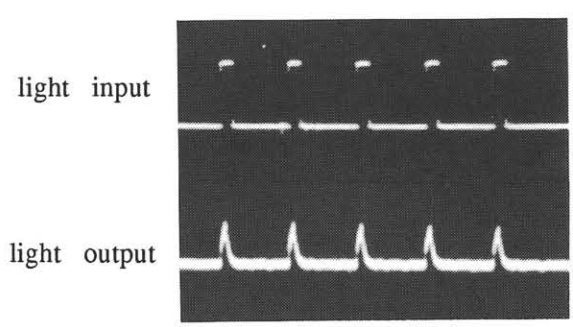

Fig. 7 Light input and light output for VSTEP1.

resonance wavelength shift as a function of the injection current is shown in Fig. 6. It is found that the resonant data signals were selectively transmitted. An internal gain for a small optical signal at a resonance wavelength was 24dB and the signal to noise ratio was 14.7dB, when the flowing current was set slightly below the threshold current.

Fig. 7 shows light input and light output transmitted through VSTEP1, which is selectively switched on by the optical pilot signal. The pulse width was 20ns.

The first optical self-routing switch proposed in Fig. 3 has been successfully demonstrated.

5. Discussion

In this experiment, TE-mode light input was used as optical data signals. When the polarization of light input changed, signal to noise ratio degraded, because a resonance wavelength for waveguide type device strongly depends on polarization of a light input. A VSTEP with a vertical cavity might be one candidate, which leads to a polarization independent optical amplifier with wavelength filtering function.

The light output pulses became sawtoothed in shape as shown in Fig. 7. This was due to gain saturation because the peak light intensity of the data signals was set high in order to obtain large signal to noise ratio.

A large saturation output power is preferable for an optical amplifier. In this experiment, saturation output power was -1dBm when the VSTEP was biased just below the threshold current. This value was larger than previously reported data[6], probably, resulting from the present current confinement structure. Current flows across 20μm-wide active region. Resultant carriers supplementation into the light propagating region might be one of the reasons for preventing reduction in carrier density accompanied by light amplification.

5. Summary

The first optical self-routing switch with a wavelength filtering function using laser mode VSTEPs has been successfully demonstrated. The development of this switch could allow the VSTEPs to realize time division, space division, and wavelength division photonic switching systems.

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