All-Optical Switching Characteristics of Semiconductor Nonlinear DFB Waveguide

Seok-Hwan JEONG and Tetsuya MIZUMOTO

Mizumoto Lab., Dept. of EEE, Tokyo Inst. of Tech.
2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8552, JAPAN
Phone & Fax: +81-3-5734-2578
E-mail : jeong@wave.pe.titech.ac.jp

Abstract: We report all-optical switching characteristics in a nonlinear GaInAsP DFB waveguide. Nonlinear GaInAsP DFB waveguide switch is fabricated. All-optical bistable switching using orthogonally and parallelly polarized control light is demonstrated in the fabricated device. In addition, we investigate theoretically and experimentally the dependence of threshold switching power on the wavelength and polarization of control light.

1. Introduction

Current switching speed of optical signal processing is limited by the speed of electronic response. All-optical switching based on an optical Kerr effect provides potential for ultrafast optical signal processing and expansion of transmission capacity [1]. With a view to integrate other photonic devices, the most promising way is to use Bragg reflector for optical feedback. In a previous works, we demonstrated all-optical set-reset [2], AND-logic function [3] in nonlinear DFB waveguides. However, previous results had some drawback. In all of those results, the signal light was unable to extract from the output temporal waveform, since the state of polarisation (SOP) of signal light was identical to that of the control one. These shortcomings can be solved by using the control light with orthogonal polarization [4] or different wavelength [5].

In this report, all-optical switching operation using orthogonally and parallelly polarized control light for TE-polarized signal is investigated in the nonlinear GaInAsP DFB waveguide. The relation between threshold switching power and control light wavelength is also discussed.

2. Operation Principle and Device Structure

In Kerr-like materials, the local refractive index is dependent on the intensity of light through the relation,

$$n=n_0+n_2I$$

Where n_0, n_2 and I indicate a linear refractive index, an intensity dependent refractive index coefficient and the intensity of light, respectively.

The schematic drawing of a strip-loaded nonlinear GaInAsP DFB waveguide discussed in this study is illustrated in Fig. 1. The grating periodicity is so designed as to satisfy Bragg reflection condition for only a signal light at a certain wavelength. When the signal is incident on the DFB region, the transmission of the light is strongly suppressed. If the control light is accompanied with the signal one, Bragg condition is not satisfied any longer and the transmission of the light becomes high.

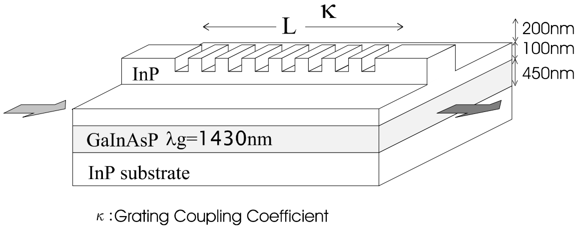

Fig. 1. Schematic drawing of strip-loaded nonlinear GaInAsP DFB waveguide

3. Experiment

The strip-loaded nonlinear GaInAsP DFB waveguide was fabricated using a GaInAsP/InP wafer in which a 450nm-thick GaInAsP core layer (λ_g=1430nm) and a 300nm-thick InP upper cladding layer were grown on a (100) non-doped InP substrate. In the fabrication of the device, a grating pattern was fabricated using electron beam lithography and CH_4/H_2-RIE ahead of waveguide formation. Grating periodicity was 232.5nm and grating length was 1.5mm. The waveguide width and height of strip was 2.5μm and 200nm, respectively.

The fabricated device was cleaved with a 5mm-length. The input port of the device was butt coupled to a polarization-maintaining fiber (PMF). An amplified spontaneous emission of EDFA was used as an optical source to measure transmission spectra. TE-polarized or TM-polarized light was incident on the input port of the device through PMF. The transmitted light was measured by spectrum analyzer. Figure 2 shows the measured transmission spectra for TE and TM modes.

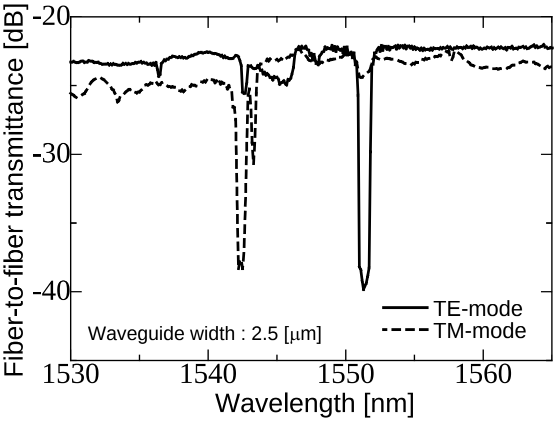

Fig. 2. Measured transmission spectra for TE and TM modes

The Bragg wavelengths for TE and TM modes were 1551.4nm and 1542.4nm, respectively. In Fig. 2, the vertical axis indicates fiber-to-fiber transmittance, which includes a coupling loss between an optical fiber and a device at two facets as well as propagation loss.

We measured intensity dependent transmission characteristics. CW tunable laser was used an optical source. Signal and control light was respectively generated by pattern generator and EO modulator. The input pulse stream was butt-coupled to the input port of the device through the PMF. The transmitted pulse stream was detected by photo detector (PD) and then measured by oscilloscope of which sampling speed was 400Msample/sec (Its sampling period is 2.5ns). In order to monitor the input pulse stream, it was detected by another PD prior to coupling to the device.

Figure 3 shows the measured all-optical bistable switching operation in the fabricated nonlinear GaInAsP DFB waveguide. Figure 3 (a) shows the input temporal waveform, where set pulses correspond to the control light and their SOP is TM-mode. The control light wavelength is 1551.78nm. A holding beam corresponds to the signal one and its SOP is TE-mode. The holding beam power and wavelength of signal light was fixed to be 11mW and 1551.78nm, respectively.

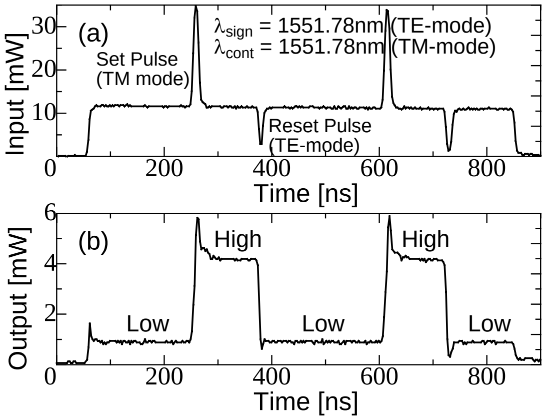

Fig. 3. All-optical bistable switching using TM-polarized control light (out of stopband of TM mode) (a) temporal input waveform and (b) temporal output waveform

In response to this input temporal waveform in Fig. 3 (a), the transmitted light was switched from low state to high state by launching set pulses. Once the transmission state moved to high state, its level was maintained irrespective of presence of the control light as shown in Fig. 3 (b). The switching power (control power) was estimated to be 23.5mW. In this case, the signal light can be separated by the use of polarization beam splitter (PBS), since the SOP of the control light is orthogonal to that of signal one.

In order to separate the signal light from the output, the PBS must be used. However, if the wavelength of TM-polarized control light is set to be in the stopband of Bragg reflector, the control light will be eliminated from the transmission port by virtue of the Bragg reflection, which enables us to extract the signal light without using any external devices like PBS. Actually, we observed experimentally that the control light was clearly removed at the output port after switching operation when the wavelength of control one was located at the stopband of TM mode.

We also investigated all-optical switching characteristics utilizing parallelly polarized control light to the signal one. The holding beam power was kept to be 11mW and its wavelength was 1551.78nm, as shown in Fig. 4.

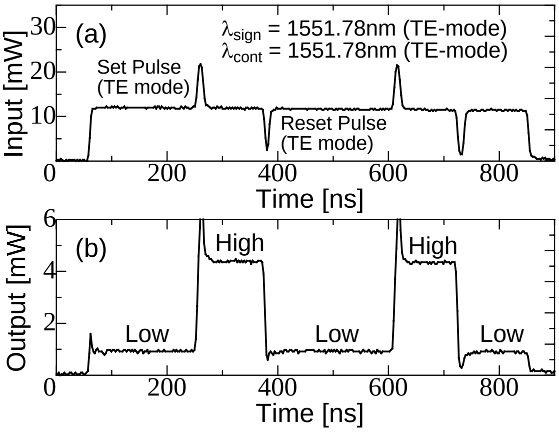

Fig. 4. All-optical bistable switching using TE-polarized control light (within stopband of TE mode) (a) temporal input waveform and (b) temporal output waveform

As shown in Fig. 4 (b), all-optical bistable switching operation was successfully obtained. However, the estimated switching power was 10mW, which is considerably lower than that of TM-polarized control light.

The minimum control power required for switching for TM-polarized and TE-polarized control light is plotted in Fig. 5 as a function of the wavelength of control light, together with measured transmission characteristics. For both TE- and TM-control light, the lowest switching power was obtained around the longer-wavelength side of respective stopband edge. However, as the wavelength of TE-polarized control light shifts to the shorter-wavelength side of stopband, the switching power was remarkably increased. In other words, the switching power strongly depends on the wavelength of control light around its stopband regions.

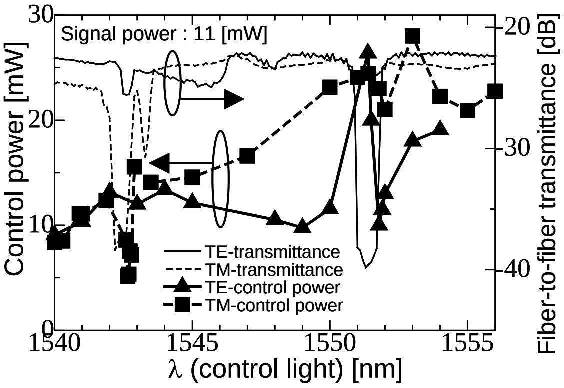

Fig. 5. Measured minimum control power for switching operation for TE- and TM-polarized control light

The wavelength dependence of switching power is caused by the intensity distribution of the control light in the grating region. The control light with the wavelength within the stopband experiences Bragg reflection. This gives rise to the intensity distribution change of control light along the propagation direction, which is different from the case where the control light wavelength is out of the stopband. This variation of intensity distribution of control light affects the required switching power. When the control light wavelength is located at the center of stopband, the effective refractive index change over the entire Bragg region becomes small, which requires larger control power to obtain refractive index change enough to switch the transmittance. It can be observed from Fig. 5 that the required switching power of TE control light is less compared with the TM case except the Bragg wavelength region. This can be attributed to the difference of nonlinear refractive index coefficient (n_2) provided by the control light with parallel or orthogonal polarization to the signal one. For purely electronic nonlinearity, the nonlinearity of orthogonally polarized control is 3 times less than that of parallelly polarized control [6]. Therefore, when the control light with polarization parallel to the signal is used, the refractive index change required for switching is obtained with lower control power.

4. Conclusion

All-optical bistable switching operation using TM-polarized and TE-polarized control light was demonstrated in the strip-loaded nonlinear GaInAsP DFB waveguide. Besides, dependence of threshold switching power on the control light was investigated.

Reference:

[1] P. L. K. Wa et al, Electron. Lett., **22**, (21), (1986)
[2] K. Nakatsuhara et al, Photon. Technol. Lett. **10**, (1), (1998)
[3] K. Nakatsuhara et al, MOC'99, pp316-319, (1999)
[4] S.-H.Jeong et al, NLO2000, TuD4, USA, pp165-167, (2000)
[5] S.-H.Jeong et al, LEOS2000, WEE4, Puerto Rico, pp663-664, (2000)
[6] P. M. Maker et al, Phys. Rev., 137, A801-A818 (1965)