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Semiconductor dispersion compensators based on asymmetrically coupled waveguides

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1. Introduction

The asymmetrically coupled waveguide has great potential as the basis for a compact form of transmission-type dispersion compensator [1]. A dispersion compensator of this kind is made of a semiconductor; this is convenient in that it allows monolithic integration with other optical devices such as ultrashort-pulse semiconductor lasers and semiconductor optical amplifiers. The compression of chirped pulses by dispersion compensation have been demonstrated for both InGaAsP and TiO_2/Si planar asymmetrically coupled waveguides [2,3]. Ridge-type waveguides are of more practical use in real optical communication systems. Accordingly, the authors have fabricated a semiconductor dispersion compensator based on a ridge-type asymmetrically coupled waveguide with mode convertors and demonstrated the compression of picosecond chirped pulses by this device.

2. Operating principle

Figure 1 gives a schematic view of the fabricated InGaAsP asymmetrically-coupled-waveguide-based dispersion compensator consisting of a dispersion compensating (DC) region sandwiched between two mode convertors. The DC region was designed so that the TE_{02} mode with a small group velocity (GV) in the large-index waveguide (WG1) and the TE_{00} mode with a large GV in the small-index waveguide (WG2) are coupled at a wavelength of 1.545 μm to form two kinds of supermodes: a symmetric supermode (in-phase coupling) and an antisymmetric supermode (out-of-phase coupling). Supermodes of this kind, formed by two modes with a large difference in GV, have a large group-velocity dispersion (GVD) because of the strongly frequency-dependent coupling ratio between the two modes. Calculated GVDs for the supermodes are shown in Fig. 2. The respective supermodes generate a normal and an anomalous GVD of equal magnitude. There is a trade-off between the GVD and its bandwidth, and the product of the two is known to be approximately proportional to the difference between the refractive indices of the two waveguides (WG1 and WG2):

$$|D_{pk}(W)| \cdot \delta\omega(W) \cong (1/2)|v_1^{-1} - v_2^{-1}| \propto \Delta n \qquad (1)$$

Here, D_{pk} is the peak value of the GVD, $\delta\omega$ is the bandwidth, v_1 and v_2 are the GVs of the two modes that form the supermodes, W is the spacing between WG1 and WG2, and Δn is the difference between the refractive indices of WG1 and WG2. An increase in the GVD can be obtained by increasing W between WG1 and WG2, though this narrows the bandwidth of the supermodes [1].

The mode convertors were designed to convert an input mode (TE_{00} mode) into the symmetric supermode in the DC region and vice versa [4]. As a result, only the symmetric supermode that has normal dispersion is excited in the DC region. The fabricated compensator can therefore compress down-chirped pulses.

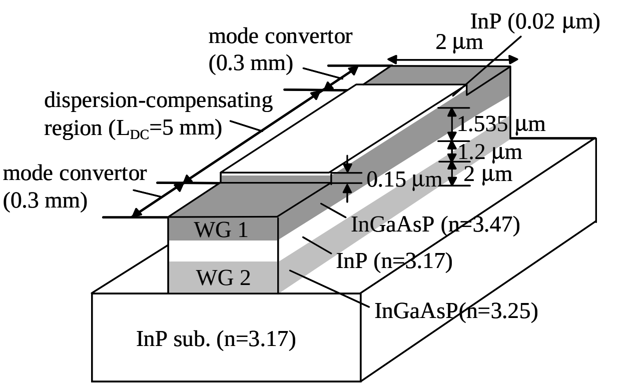

Fig. 1 Schematic view of fabricated InGaAsP ridge-type asymmetrically coupled waveguide with mode convertors (n denotes refractive index).

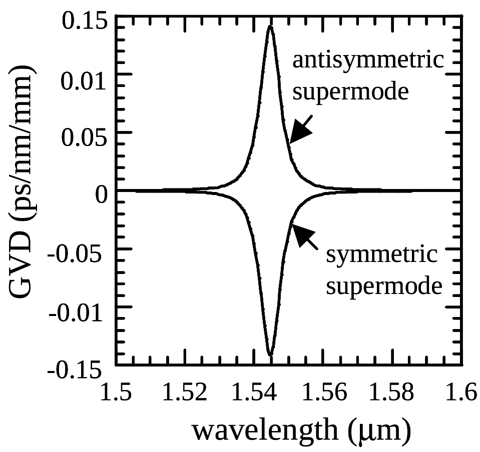

Fig. 2 Calculated GVDs for the supermodes.

3. Experimental results

Pulse-compression experiments for the device shown in Fig. 1 were conducted with down-chirped pulses, which were focused and detected by lensed fibers; the autocorrelation (ac) signals of the output pulses were measured from the detected signals. In the experiments, we used down-chirped pulses generated in the following way. A tunable mode-locked fiber ring lasers (pulse width: 1.2 ps (assumed a $sech^2$-shaped pulse) , tunable range of central wavelength: 1.53-1.56 μm, spectral bandwidth: 2.4 nm, repetition rate: 20 MHz, average power: 3 mW) was used as an ultrashort-pulse source. We attenuated the power of pulses from the fiber ring laser by an optical attenuator to avoid optical nonlinear effects, and then passed the attenuated pulses through a single-mode fiber with dispersion of about 2 ps/nm in order to generate down-chirped pulses. The average power of the pulses from the single-mode fiber was increased up to 2 mW by a fiber amplifier. The full-width at half-maximum (FWHM) of the ac signal of the input pulse (δt) was 8.3 ps. The average power (2mW) was selected to minimize the loss due to two-photon absorption and maximize the output power.

Figure 3 shows the measured ac signals of the output and input pulses. The compression ratio: C_p is 0.55. The minimum FWHM of the ac signal was obtained for the input pulse with a central wavelength of 1.55 μm.

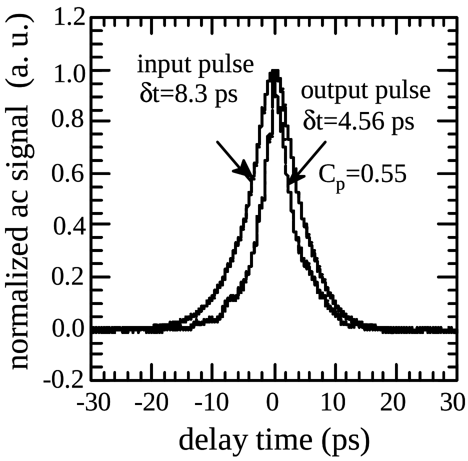

Fig. 3 Measured autocorrelation (ac) signals (C_p denotes the compression ratio, defined as output-pulse width/input-pulse width, and δt denotes the FWHM of the ac signal).

4. Discussion

We carried out numerical simulation to replicate and investigate the experimental result shown in Fig. 3. In this simulation, we manipulated two parameters of fit to approach the experimental result as closely as possible. One is the length of the DC region (L_{DC}). The other is the ratio of power between the excited symmetric supermode in the DC region and the input mode, denoted by m_s. We assumed that the input mode was fully converted to the supermodes in the DC region, namely, m_s+m_a=100% where m_a is the ratio between the power of the excited antisymmetric supermode in the DC region and the input mode. In the case where only the symmetric supermode is excited by the mode convertor, m_s=100% (m_a=0%). m_a=m_s=50% when the mode convertors are completely ineffective. The input pulse we used in the calculation was a linear down-chirped $sech^2$-shaped pulse with the same FWHM of ac signal and bandwidth as the pulse used in the experiment.

Figure 4 shows the calculated ac signal that best fit the experimental result shown in Fig. 3. We used L_{DC} = 9 mm and m_s=70% (m_a=30%). This discrepancy in L_{DC} is acceptable when we consider the possible sources of imprecision in the waveguide parameters of the fabricated device and the chirped characteristic of the input pulse.

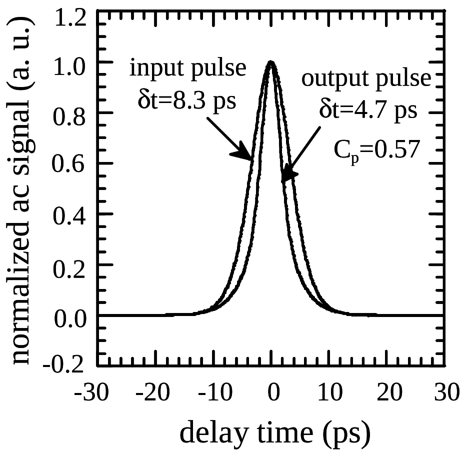

Fig. 4 Calculated autocorrelation (ac) signals (notation is the same as in Fig. 3).

5. Summary

We have fabricated InGaAsP dispersion compensators based on ridge-type asymmetrically coupled waveguides and used them in the compression of picosecond chirped pulses.

Acknowledgements

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References

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