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Semiconductor asymmetrically coupled waveguides for tunable dispersion compensation

Yong Lee, Aki Takei, Takafumi Taniguchi and Hiroyuki Uchiyama
Central Research Laboratory, Hitachi, Ltd., 1-280 Higashi-Koigakubo, Kokubunji-shi, Tokyo 185-8601, Japan
Phone: +81-42-323-1111 E-mail: yongl@crl.hitachi.co.jp

1. Introduction

Dispersion compensators based on asymmetrically coupled waveguides are promising as compact waveguide-type dispersion compensators.[1] The authors have previously fabricated a dispersion compensator consisting of an InGaAsP ridge-type asymmetrically coupled waveguide with mode converters and demonstrated the compression of picosecond chirped pulses by this device.[2]

The fine tuning of dispersion is required for efficient dispersion compensation. In the present work, we demonstrate the possibility of a tunable dispersion compensator based on asymmetrically coupled waveguides with temperature control.

2. Operating principle

Figure 1 schematically depicts the dual vertically coupled asymmetric InGaAsP/InP ridge waveguides. This structure was designed so that the TE_{02} mode with a small group velocity (GV) in the large-index (n_1) waveguide (WG1) and the TE_{00} mode with a large GV in the small-index (n_1) waveguide (WG2) are coupled at a wavelength of around 1.55 μm. These modes are coupled both symmetrically (in-phase) and antisymmetrically (out-of-phase). Coupled modes, formed by two component modes with a large difference in GV, have a large group-velocity dispersion (GVD) because of the strongly wavelength-dependent coupling ratio between the two component modes. The symmetrically and antisymmetrically coupled modes have normal and anomalous GVD, respectively, and equal magnitude.[1]

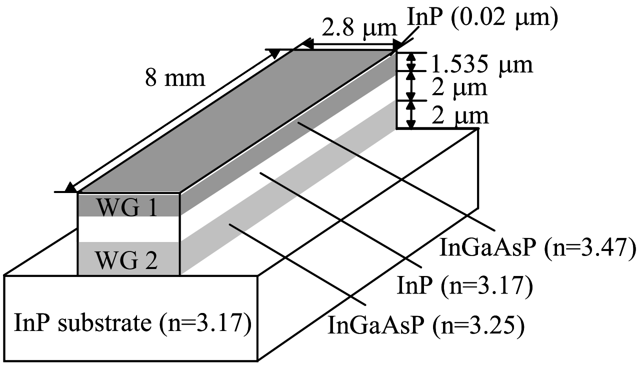

Fig. 1 Schematic view of dual vertically coupled InGaAsP/InP asymmetric ridge waveguides (n denotes refractive index).

Calculated GVDs of the coupled modes for various temperature shifts are shown in Fig. 2. In this calculation, we assumed that temperature has the same effect on refractive index in all three layers, and that the variation in refractive index (n) with temperature (T), dn/dT, is 2×10^{-4}/℃.[3] Variation in temperature changes the wavelength at which resonant coupling between the two modes occurs, because the change in refractive index changes the effective indices of the two component modes. This shifts the peak wavelength of the GVD (λ_r), as is shown in Fig. 2. The variation in λ_r with temperature, $d\lambda_r/dT$, is 0.04 nm/℃. This effect of temperature on the GVD can be used for the fine tuning of dispersion compensation.

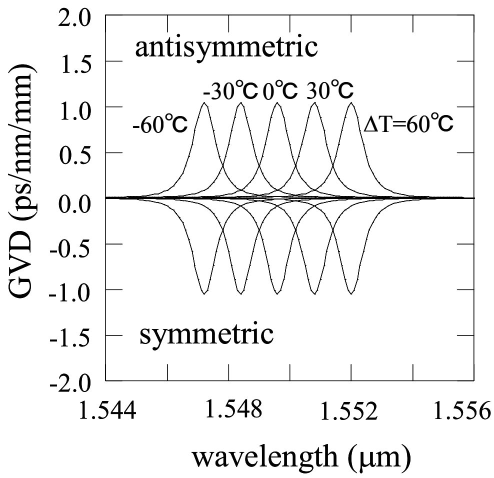

Fig. 2 Calculated GVDs of the coupled modes for various changes, ΔT, in temperature.

3. Experimental results

Pulse-compression experiments for the waveguide illustrated in Fig. 1 were conducted with down-chirped pulses, which were focused and detected by lensed fibers; the autocorrelation signals of the output pulses were measured from the detected signals. We generated down-chirped pulses for the experiments in the following way. A mode-locked fiber-ring laser (pulse width: 1.5 ps, central wavelength λ_c: 1.55 μm, spectral bandwidth: 2.2 nm, repetition rate: 20 MHz, average power: 1 mW) provided an ultrashort-pulse source. The power of the pulses from the fiber-ring laser was attenuated to avoid nonlinear optical effects, after which the attenuated pulses were passed through a single-mode fiber with GVD of about +6 ps/nm, producing down-chirped pulses. The down-chirped pulses were amplified to 2 mW by a fiber amplifier. This level of power was chosen to minimize the loss due to twophoton absorption and to maximize the power of the output pulses. The full-width at half-maximum (FWHM) of the autocorrelation signal for the input pulse was 40.1 ps, which corresponds to a pulsewidth of 25.78 ps given the assumption of a $sech^2$-shaped pulse. The input pulse was TE-polarized by a polarization controller and focused on the lower waveguide, WG 2. The temperature of the waveguide was controlled by changing the temperature of the waveguide holder, i.e. the platform on which the waveguide was placed.

Figure 3 shows measured autocorrelation signals for the output pulses at different temperatures. As we expected, the width of the autocorrelation signal varied with the temperature of the waveguide. The compression ratio, C_p, varies in the range from 42.7% to 84.2%.

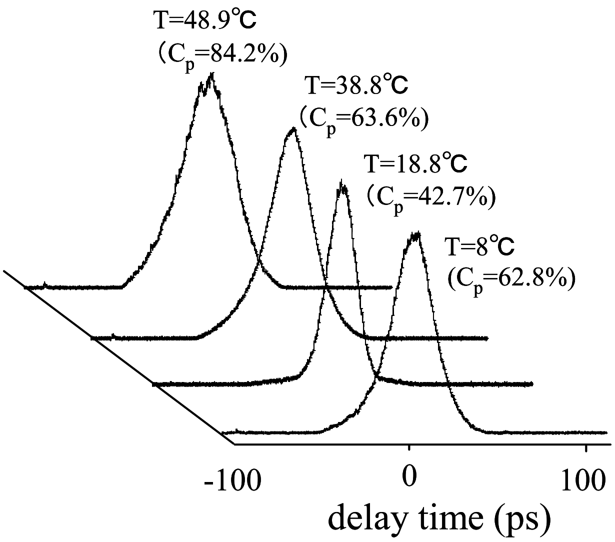

Fig. 3 Measured autocorrelation (ac) signals at different temperatures (C_p denotes the compression ratio, defined as the ratio of δt for output pulse to δt for input pulse, where δt denotes the FWHM of the ac signal).

4. Discussion

We carried out numerical simulation to replicate and investigate the experimental results. Figure 4 shows the measured and calculated FWHM values of the autocorrelation signals for the output pulses as functions of temperature. These calculated results were obtained under the following conditions. The input pulse was a linear down-chirped $sech^2$-shaped pulse with the same FWHM of autocorrelation signal and bandwidth as the pulses used in the experiment. To take the effective reduction and broadening of the GVD due to fluctuations in refractive index and layer thickness in the direction of light propagation into account, we used GVD curves with peak value and bandwidth 1.56 times smaller and 1.33 times wider, respectively, than those of the GVD curves shown in Fig. 2. The shift in peak GVD wavelength, $d\lambda_r/dT$, was 0.025 nm/℃, less than the ideal 0.04 nm/℃. The selection of a smaller shift reflects the fact that the temperature-controlled waveguide holder is only 3-mm long but the waveguides are 8-mm long. We assumed that the input mode was fully converted to the coupled modes. The ratio of power between excited symmetrically and antisymmetrically coupled modes was calculated for $\Delta\lambda(T)=\lambda_c-\lambda_r$ (T, where T is temperature). $\Delta\lambda$ was 0.62 nm at 18.8℃. The waveguide length required to obtain a match between the experimental and calculated results was then 14 mm, 1.75 times the length of the actual waveguide. This discrepancy in the waveguide length is acceptable when we consider the possible sources of imprecision in the waveguide parameters of the fabricated device and the chirping characteristic of the input pulse.

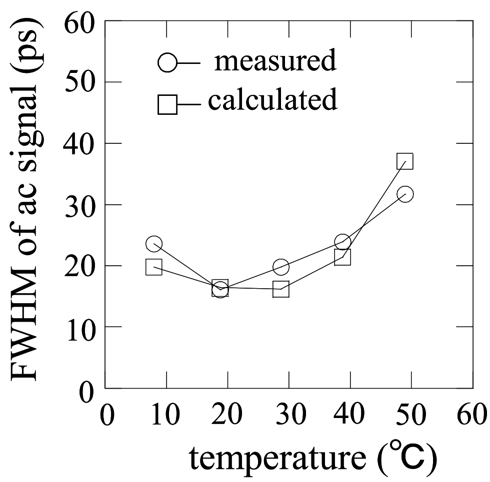

Fig. 4 Measured and calculated FWHM of the ac signals for the output pulses as functions of temperature.

5. Summary

We have demonstrated temperature tuning of dispersion compensation with asymmetrically coupled InGaAsP/InP waveguides and thus demonstrated the structure's potential as a tunable dispersion compensator.

Acknowledgements

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References

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