Widely Tunable Time Delay Control in Phase-Shifted Gain/Loss Coupled Distributed Feedback Structures

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Abstract: Group delay behavior of phase-shifted DFB structures with gain/loss coupling is numerically analyzed below the lasing threshold condition. It is demonstrated that these structures can be used as widely tunable optical time delay lines.

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1. Introduction

There has been a great deal of interest in tunable optical time delay lines where the group velocity v_g of a pulse can be controlled over a wide range of values [1]. Applications of optical time delay lines include optical packet switching and analog and digital optical signal processing among others.

In this report we analyze the potential of realization of slow and fast light delay lines using tunable optical filters based on distributed feedback (DFB) laser structures. These grating-embedded semiconductor devices are very popular active optical filters since they are suitable for monolithic integration with other semiconductor optical devices such as laser diodes, optical switches and photo-detectors [2]. In gain coupled DFB (GC-DFB) structures the coupling between the contra-propagating modes is achieved by phase-matching them with a periodic perturbation of the imaginary part of the refractive index (gain and/or loss). With the progress in DFB laser fabrication technology, it is now possible to build current-pumped GC-BFB structures with gain/loss gratings [3]. The gain-coupling coefficients of this structure can be adjusted by controlling the strength of the injection current.

Tunable optical filters using GC-DFB structures with an external phase shift control have been proposed and analyzed recently [3]. However, this study has been restricted to the CW regime, and no detailed analysis of the dispersive properties of these devices has been provided. In this report we present the analysis of the dispersive characteristics of GC-DFB structures assuming a switchable phase shift in the middle of the structure and a tunable non-modulated gain/loss. By adjusting these parameters it is possible to control the group delay of propagating pulses from deeply subluminal to strongly superluminal regimes with minimum distortions of the pulse.

2. Device structure

The analyzed structure of a gain coupled DFB filter is shown in Fig.1a and consists of an unperturbed Δ–long guide which is sandwiched between two active L-long GC-DFB sections along the longitudinal axis z**.** We assume that the structure consists in a single-mode waveguide with a ***uniform*** periodic spatial modulation of the gain $\alpha(z)$ (gain/loss grating) superimposed to a non-modulated tunable gain/loss background α_0 (DC gain/loss). For simplicity we will neglect any gain-induced variation of the refractive index within the grating region. The operating wavelength will always be located at the Bragg wavelength.

3. Numerical results

The structure can be analyzed by using the coupled-mode theory. The gain/loss grating induces coupling between the forward propagating mode and the backward propagating mode in the waveguide. The structure is operated in an active filter regime below the lasing threshold, thus allowing us to use the transfer matrix approach to describe its complex spectral transmission. The output pulses are computed by taking the convolution between the transmission spectrum and a standard Gaussian pulse. In all cases, the Gaussian shape of the pulse is qualitatively preserved throughout the structure.

3.1. Imaginary Bragg grating with zero-phase shift (Δ=Λ): slow light regime

Fig.1b demonstrates the transmission spectrum of the GC-DFB with a total length of $2L+\Delta$ = 3 mm, a grating strength of $\kappa L = 0.15\pi$ (κ is the grating coupling coefficient) and a period of Λ = 0.3 μm built in a single-mode guide (effective index of n_{eff} = 2.59) and for different values of the DC gain. As one can see, the transmission exhibits a strong gain peak at the resonance wavelength. At the same time, the structure provides high group time delay as shown in Fig.1d, where we present the group time delay normalized with respect to the time of propagation through the unperturbed guide (T_R) as a function of DC gain (dotted curve).

3.2. Imaginary Bragg grating with π-phase shift ($\Delta=\Lambda/2$): fast light regime

Fig.1c demonstrates the transmission spectrum of the same GC-DFB as the one described in 3.1 but with a phase shift of π and different values of DC gain. The introduction of a π-phase shift in the structure transforms its transmission spectrum from a single amplification peak (Fig.1b) at the Bragg wavelength into a spectrum with two symmetrical amplifying peaks located on each side of the Bragg wavelength. This spectrum is very similar to that previously obtained by relatively complex laser-induced processes in inverted atomic media [4, 5]. As shown in these previous studies, a pulse centered at the central (Bragg) wavelength can propagate along the structure with group velocity larger than the speed of light in vacuum without losses and without undergoing any significant temporal shape distortion; this condition is satisfied as long as the pulse bandwidth is sufficiently narrow so that to lie in the spectral region between the spectral gain lines. In regards to our specific numerical example, Fig.1d shows that when the DC gain is varied within such a structure, the pulse experiences a strong advancement, with a maximum group velocity about two times larger than that in the unperturbed guide just before reaching the lasing threshold.

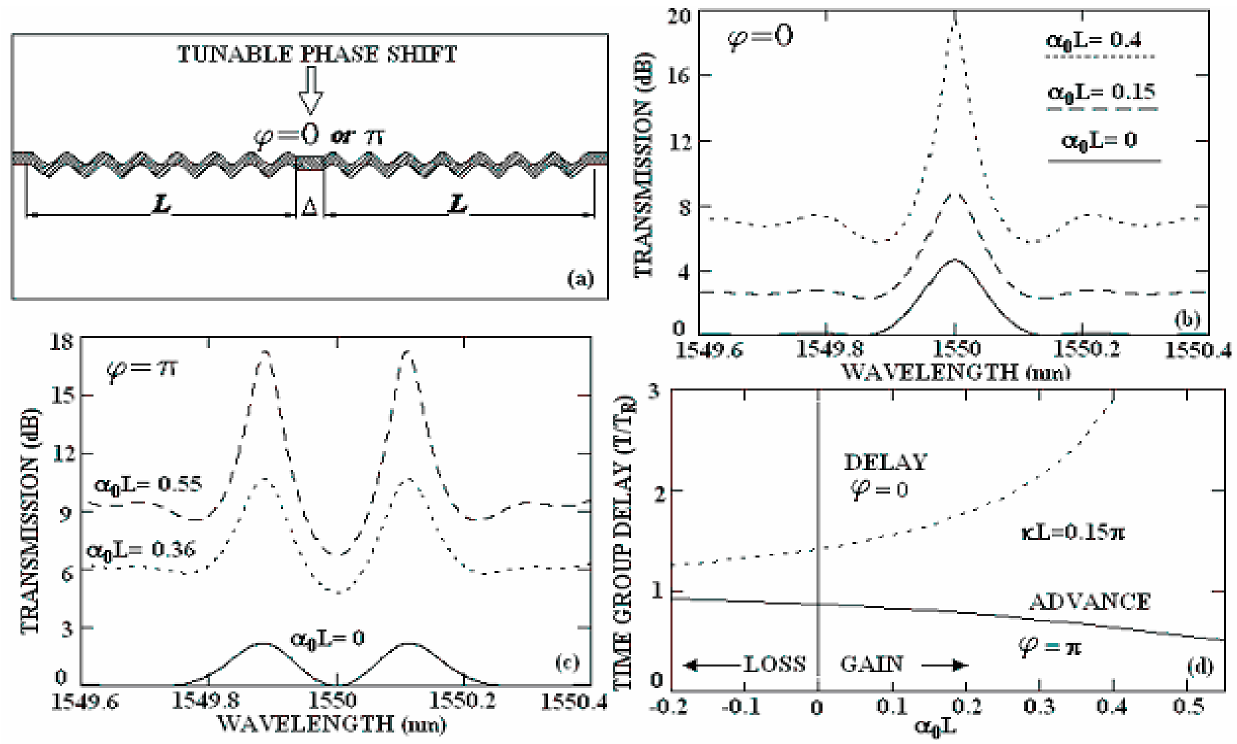

Fig.1. (a) Proposed structure of GC-DFB tunable optical filter; transmission characteristics of 3 mm long GC-DFB structure with κL=0.15π with zero phase shift (b) and π-phase shift (c) for different values of the DC gain $\alpha_0 L$;(d) the grope delay of a 150 ps FWHM Gaussian pulse as a function of the DC gain/loss $\alpha_0 L$.

The GC-DFB structures with non-zero phase shift provides also a number of unusual spectral and dispersion characteristics near the lasing threshold that will be discussed in the conference. In particular, GC-DFB structures demonstrate strong amplification even with zero DC gain/loss, when segments of gain in the grating are compensated by equal segments of loss.

4. Conclusion

We have shown that by switching the phase shift between 0 and π between two GC-DFBs and by adjusting the DC gain, it is possible to achieve either negative or positive group delays (with respect to that in the unperturbed guide).

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4. References

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