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PICOSECOND SPECTRA OF GAIN-SWITCHED QUATERNARY LASERS

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Abstract

Detailed analysis of picosecond pulse generation in 1.55μm lasers is reported. Large dynamic linewidth (~100GHz) is predicted for lasers driven to 10 times threshold. Spectra emitted by lasers biased below and above threshold are compared, and the spectral purity of the optical pulse is shown to improve considerably when a pre-bias condition above threshold is chosen.

1. Introduction

Recent successful generation of picosecond optical pulses from 1.3µm InGaAsP injection lasers by gain-switching [1 , 2] brings nearer the prospect of optical communication at very high bit rates in excess of 10Gb/s [3]. In view of this application, detailed studies of transient laser characteristics under picosecond modulation conditions become increasingly important. It has been observed that 1.3µm lasers operate multimode and exhibit a considerable dynamic wavelength chirping (~2.4nm) when modulated by 80ps current pulses [4]. While this behaviour does not affect transmission properties in 1.3µm fibres [5], it may be detrimental to the performance of non-dispersion-free 1.55µm systems.

In this contribution the temporal behaviour of picosecond pulses generated by gain-switching in 1.55µm lasers is analysed by solving the multimode rate equations [6]. We consider a laser structure with a built-in lateral waveguide, neglecting diffusion and assuming spatially-uniform photon and electron populations in the active region. The spontaneous emission coupled into each lasing mode and the gain at each mode wavelength are calculated from a simple model [7] assuming band-to-band recombination between parabolic bands with no k-selection. An effective bandgap energy is used to account for the bandgap shrinkage effect. The dynamic wavelength shift due to free-carrier-induced variations of the refractive index is also included in the calculations. We use a value of $d\mu/dn = -2.8 \times 10^{20}$ cm^3 where μ is refractive index and n is electron concentration. This value is obtained when the magnitude of the free-carrier-induced wavelength shift observed experimentally [8 , 9] is combined with the threshold electron concentration estimated from our model for gain. We consider lasers with cavity length of 50μm, since single-mode operation is facilitated in short-cavity lasers due to larger mode spacing [10]. The reflectivities of coated laser facets are taken as 0.6 and 0.9. A pre-bias current close to the threshold current is assumed and a transient response to a triangular pulse current is investigated. Short pulse current pumping rather than strong sinusoidal RF modulation has been modelled as the former technique offers better stability in practice [11] and yields shorter optical pulses [12]. The computed results correspond to a buried-heterostructure laser with the width and thickness of the active region 5μm and 0.3μm, respectively.

2. Discussion of Results

As a first example we examine the case of a laser biased at 99% of threshold and driven to 10 times threshold with a pulse width of 50ps (measured at the pulse base). The time-resolved power spectrum of radiation emitted through the lower-reflectivity mirror is shown in Figure 1 together with the current injected into the active region (marked with a broken line). The top solid curve represents the time evolution of the total power of 9 modes included in the calculations. The FWHM of the optical pulse is 16ps. The curves designated 0, +1 and -1 correspond to the central, adjacent shorter-wavelength and adjacent longer-wavelength longitudinal modes, respectively. Note that both 0 and +1 modes are almost equally excited, although in the steady state the mode 0 would by far dominate (the parameters of the laser were selected in such a way that the above-threshold steady-state operation would be single-mode, with the modes +1 and -1 having equal powers; at 2 times threshold the mode 0 would be ~530 times stronger than either of the adjacent ones).

It is easier to assess the modal content of the transient spectrum with the aid of Figure 2, showing for each of 5 modes the evolution of the photon density expressed as a fraction of the total photon density. The broken curve in this figure depicts the dynamic wavelength shift $\lambda(t) - \lambda(0)$ for the central mode, with $\lambda(0) = 1.5392\mu m$. Its mirror image (the minimum interchanged with the maximum) would represent the evolution of carrier concentration, since the wavelength chirping is caused by free-carrier induced variations of the refractive index. The fast depletion of carrier concentration (and the shift towards longer wavelength by 0.8nm) occurs at the same time as the optical power approaches its maximum, hence the optical pulse is considerably broadened with a dynamic linewidth of ~100GHz. The complex behaviour of the relative photon density in different modes revealed by Figure 2 can be explained by shifts of the gain spectrum that accompany the variation of the carrier concentration.

The spectral purity of the optical pulse improves substantially when the laser is pre-biased slightly above threshold and tuned to the single-mode condition. The domination of the central mode persists even though the mode +1 experiences a higher gain, since a larger initial number of photons in mode 0 stimulates an intense emission. Figure 3 shows the time dependence of the relative photon density and of the wavelength shift for a laser with the same parameters as previously, but pre-biased at 1.03 times threshold. The mode 0 dominates clearly throughout the pulse, and near the top of the photon density spike it is 12 times stronger than the mode +1. This result is similar to experimental observations of single-mode pulsed operation of AlGaAs lasers pre-biased above threshold [13].

When the current pulse is too long, a second photon density spike will develop. Figure 4 illustrates an intermediate situation with the pulse width 150ps and other parameters kept the same as for Figure 1. As can be deduced from the wavelength-chirping curve, the electron concentration after reaching a minimum narrowly over-shoots the threshold value, thus giving rise to a long tail in the optical pulse.

3. Conclusion

In conclusion, results of the reported calculations show that large wavelength chirping up to 1nm is expected in lasers driven to 10 times threshold. Single optical pulses with peak power of several tens of milliwatts and half-width of ~15ps can be excited by injection of a current pulse with length not exceeding 120ps. While it is practically impossible to ensure a single-mode emission from pulsed free-running lasers biased below threshold, large improvement can be achieved when a pre-bias condition just above threshold is chosen.

4. Acknowledgements

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References

[1] P.-L. Liu, C. Lin, I.P. Kaminow and J.J. Hsieh, IEEE J. Quantum Electron. QE-17 (1981) 671.

[2] N. Onodera, H. Ito and H. Inaba, Electron. Lett. 18 (1982) 811.

[3] A. Alping, T. Andersson, R. Tell and S.T. Eng, Electron. Lett. 18 (1982) 422.

[4] C. Lin, T.P. Lee and C.A. Burrus, Appl. Phys. Lett. 42 (1983) 141.

[5] C. Lin, A. Tomita, A.R. Tynes, P.F. Glodis and D.L. Philen, Electron. Lett. 18 (1982) 882.

[6] G.H.B. Thompson, Physics of Semiconductor Laser Devices, Wiley, Chichester, 1980.

[7] M.Osiński and M.J. Adams, IEE Proc. I, Solid State & Electron Devices 129 (1982) 229.

[8] K. Kishino, S. Aoki and Y. Suematsu, IEEE J. Quantum Electron. QE-18 (1982) 343.

[9] J.C. Bouley, J. Charil, Y. Sorel and G. Chaminant, Paper 42, Eighth IEEE International Semiconductor Laser Conf., Sept. 13-15, 1982, Ott wa, Canada.

[10] C.A. Burrus, T.P. Lee and A.G. Dentai, Electron. Lett. 17 (1981) 954.

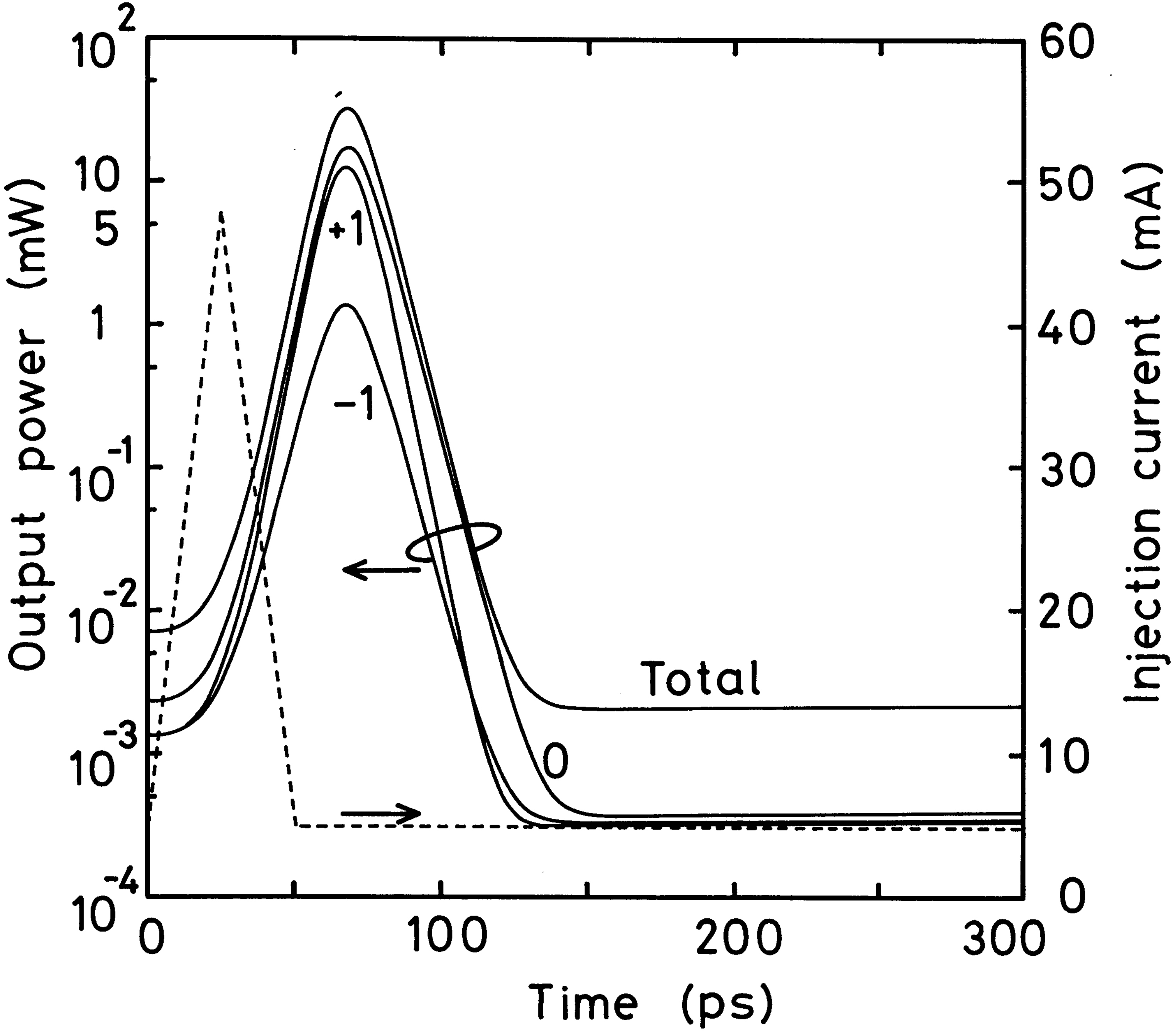
[11] C. Lin, P.L. Liu, T.C. Damen, D.J. Eilenberger and R.L. Hartman, Electron. Lett. 16 (1980) 600.

[12] J.P. van der Ziel and R.A. Logan, IEEE J. Quantum Electron. QE-18 (1982) 1340.

[13] M.A. Duguay and T.C. Damen, Appl. Phys. Lett. 40 (1982) 667.

Figure Captions

Figure 1	Output power (solid lines) and current-pulse shape (broken line) for a laser driven from 99% to 10 times threshold by a 50ps pulse.
Figure 2	Relative photon density (solid lines) and wavelength chirping (broken line) for the same case as Figure 1.
Figure 3	Relative photon density (solid lines) and wavelength chirping (broken line) for a laser driven from 1.03 to 10 times threshold by a 50ps pulse.
Figure 4	Output power (solid lines) and wavelength chirping (broken line) for a laser driven from 99% to 10 times threshold by a 150ps pulse.


Output power (mW)
10^2
10
5
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Injection current (mA)
60
50
40
30
20
10
0
Time (ps)
0
100
200
300
+1
-1
0
Total

[illegible]

Fig. 1

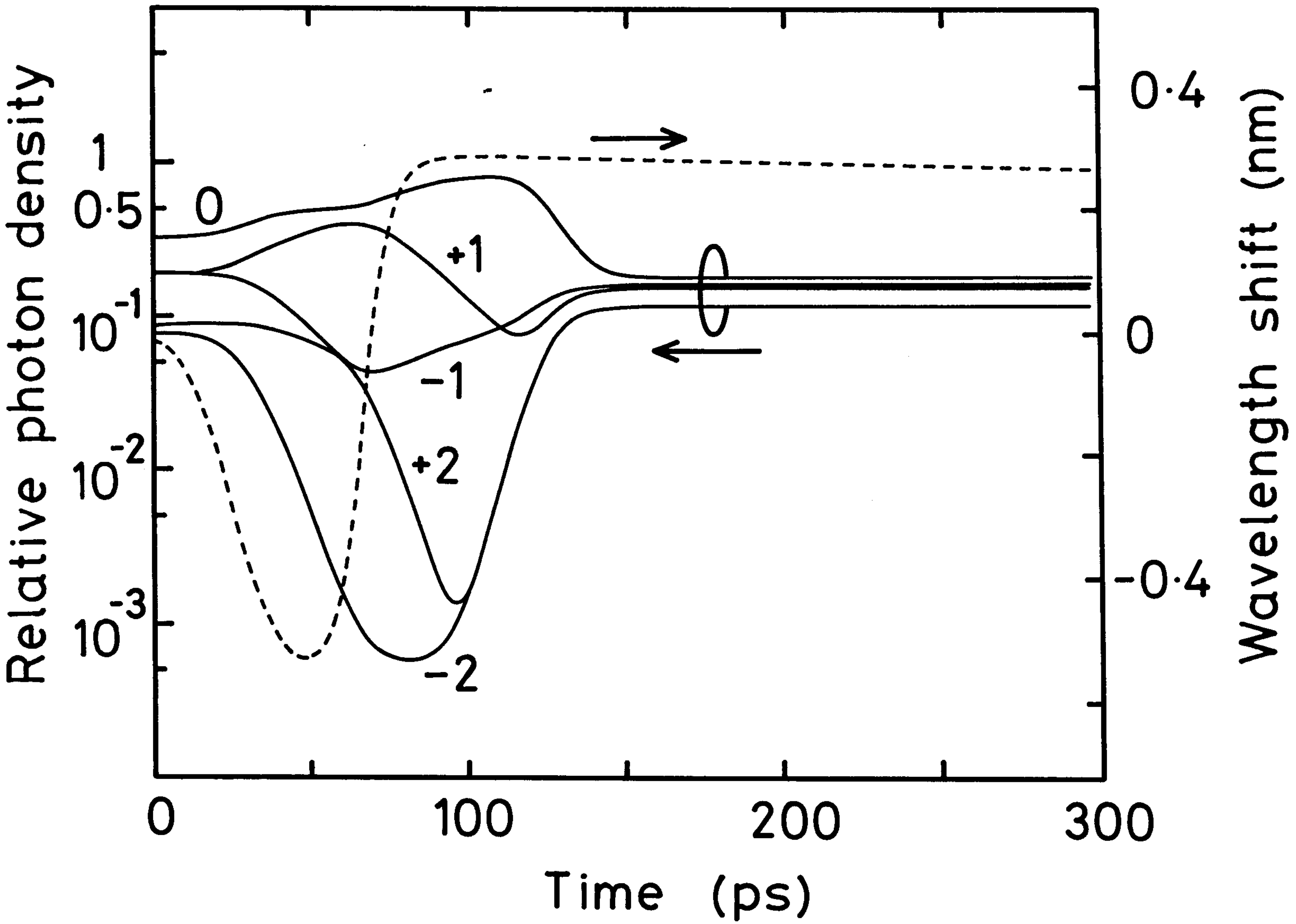


Fig. 2

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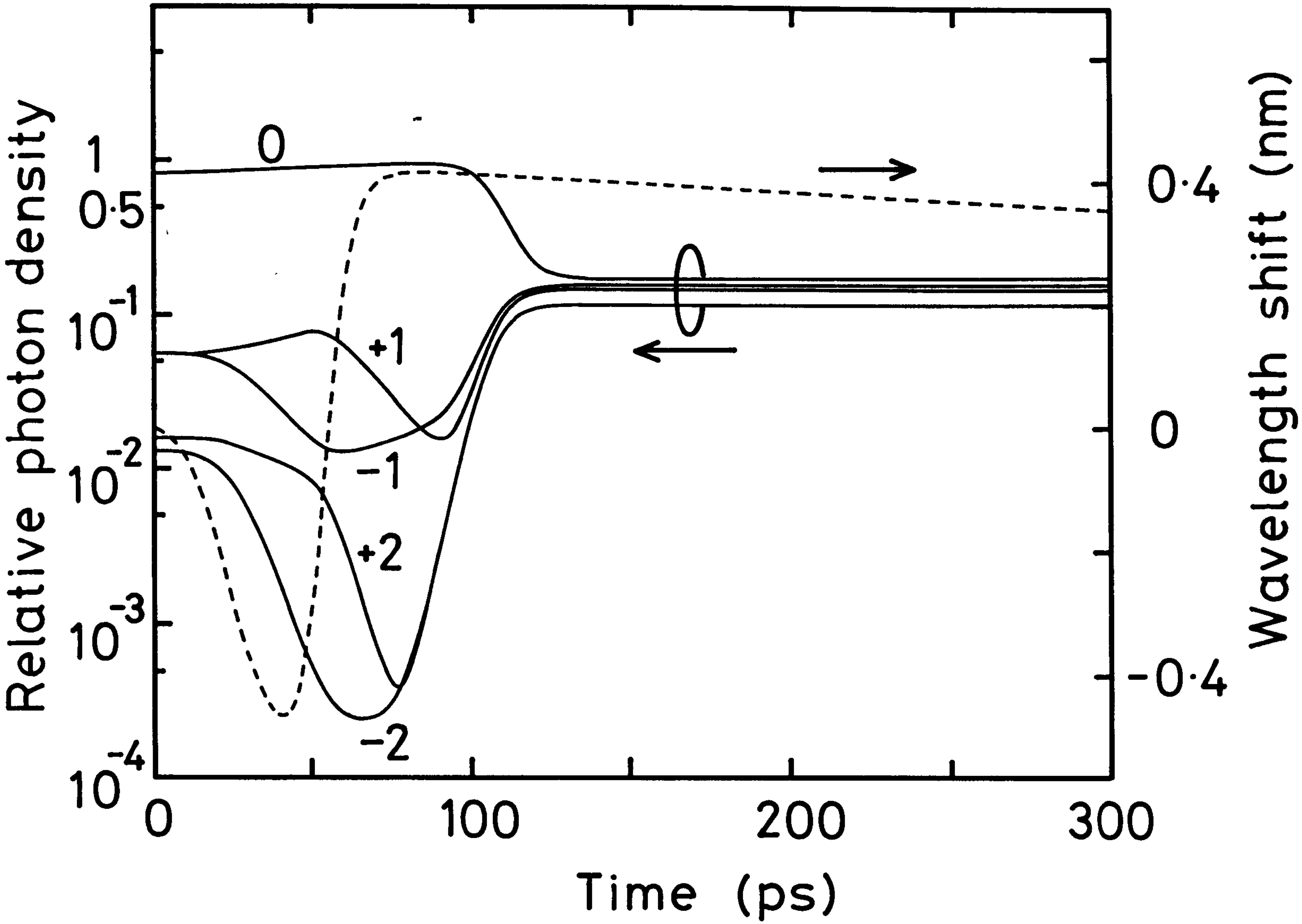

Fig. 3

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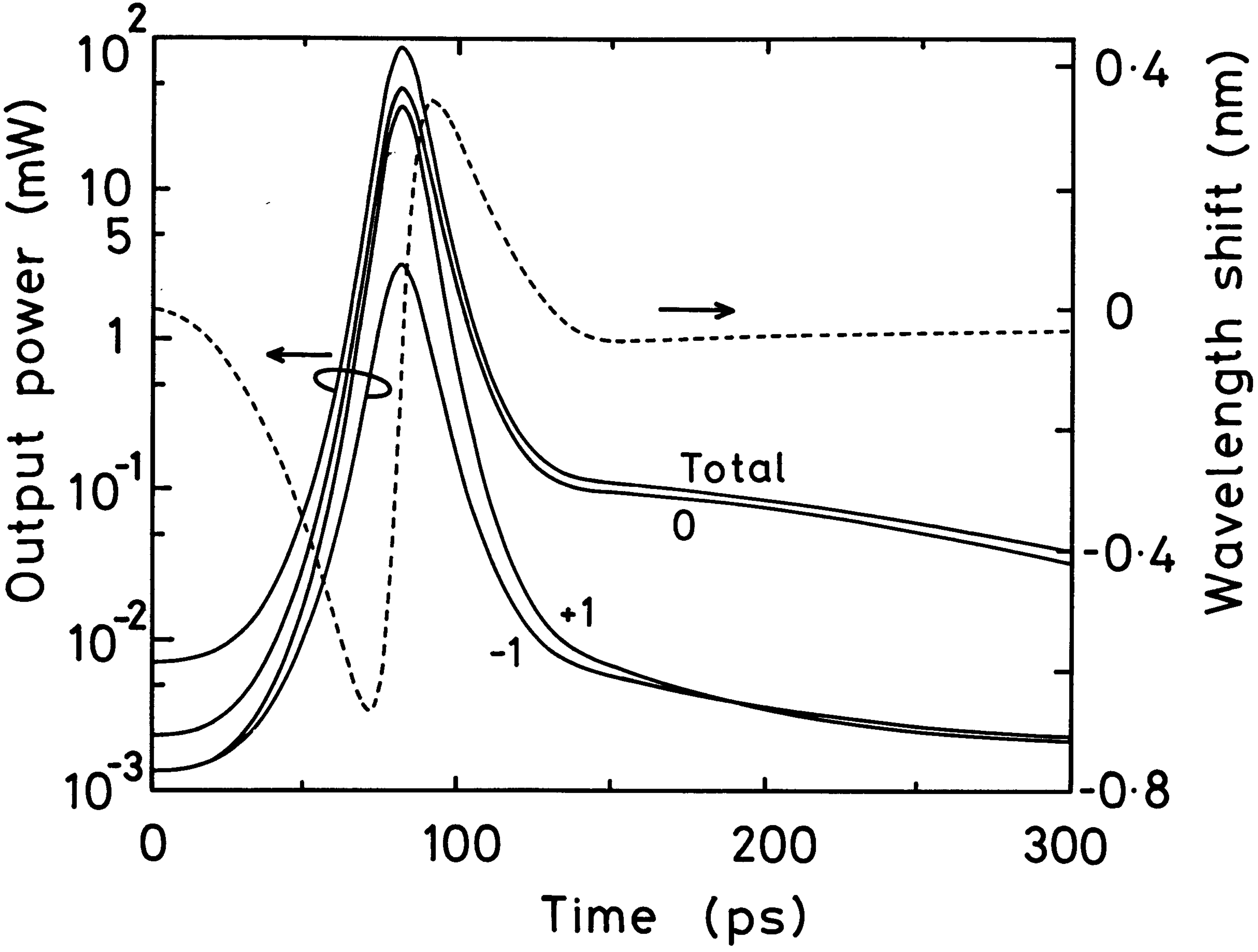

Fig. 4

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