Performance: The new synchroniser and the conventional schemes were simulated on a memoryless binary symmetric channel. The following table shows the results obtained with a ... 1010 preamble of length 17 and a sync pattern of length 16. The patterns used for the conventional scheme were taken from Reference 1. The optimal decision thresholds were found by trial and error.

The E_b/N_0 ratio [in dB] is computed from the bit error probability P_b assuming an additive white Gaussian noise channel with antipodal signalling.

The table shows the channel error probability P_b and the E_b/N_0 which is necessary for the different schemes to reach a certain sync error probability P_{sync}.

	P_b (E_b/N_0 in dB) needed to achieve P_{sync}			
	Conventional method with different patterns			New method
P_{sync}	B40C	B433	C407	54C7
0·49	0·24 (−6·0)	0·24 (−6·0)	0·21 (−5·0)	0·30 (−9·0)
0·16	0·15 (−2·8)	0·15 (−2·8)	0·12 (−1·6)	0·20 (−4·4)
0·015	0·06 (0·9)	0·06 (0·9)	0·04 (1·9)	0·10 (−0·9)
0·001	0·03 (2·6)	0·03 (2·6)	0·01 (4·2)	0·05 (1·3)

Conclusions: The simulation results show that for low signal to noise ratios the improvement of the new synchronisation scheme can be up to 3 dB when compared with the conventional method. Furthermore the simulations show that the pattern proposed in Reference 1 gains between 1 and 2 dB compared with the CCIR pattern C407, but compared with the pattern B433 the improvement is not significant.

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Reference

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ENHANCED DAMPING OF LASER DIODE RELAXATION OSCILLATIONS FROM REVISED RATE EQUATIONS

Indexing terms: Lasers and laser applications, Semiconductor lasers, Relaxation

The standard rate equations are incomplete when the optical cavity conductance depends on the optical frequency at the operating point. Corrected rate equations are given in the paper, that involve an action of frequency back on the amplitude. The number of relaxation oscillations is found to be much smaller than that calculated from standard rate equations when the optical wave is weakly index guided, as in CSP lasers. The revision of the rate equations proposed in the paper may affect most laser characteristics.

The usual rate equations[1,2] describe the time evolution of carrier numbers and stored energy, or equivalently of the number of photons in the laser cavity, defined as the region of space located between the end facets. This cavity contains media with optical gain, and perhaps loss. There exists, however, no general expression for the stored electromagnetic energy in a medium with gain or loss in terms of the medium complex permittivity and its first derivative with respect to frequency. Such an expression exists only for gainless lossless media. Furthermore, the concept of stored energy is irrelevant to the basic laser operation. To prove that point, a simple example suffices: suppose that the laser cavity contains a matched transmission line. The length of that line has no influence on the laser operation since it brings back its characteristic impedance at any optical frequency. Yet, the number of photons in the cavity can be made arbitrarily large merely by increasing the length of that transmission line. The parameter to be used is power, or rate of photon generation, rather than energy. Note that the simple linear relationship $W = P\tau_p$ between these two quantities, where τ_p is called the 'photon lifetime', is not valid in general. In fact, W may fluctuate even if P does not.

In this letter the laser is modelled as a negative admittance $-Y_a(N)$ function of the carrier number N, in parallel with a linear admittance $Y(\nu)$ at optical frequency ν. This model is appropriate at least to the case of thin active slabs.[3]

Let V denote the voltage across the circuit and I the driving current. These are complex numbers defined with respect to some conveniently chosen real frequency ν_0. They may vary slowly in time. The circuit equation is

$$[Y(\nu) - Y_a(N)]V = I \quad (1)$$

$I(t)$ is the Nyquist noise current associated with the active conductance G_a, but in this letter we do not consider noise and set $I = 0$. Differentiating eqn. 1 we obtain

$$\delta\nu(t) = (Y_N/Y_\nu)\,\delta N(t) \qquad \delta\nu \equiv \delta + i\eta \quad (2)$$

where the frequency deviation $\delta\nu$ from ν_0 has been split into its real and imaginary parts. The concept of complex frequency has been used before in that field.[4–6] The subscripts N or ν denote differentiation with respect to these quantities, the resulting expressions being evaluated at the steady-state carrier number N_0 and oscillation frequency ν_0, and we set in general $Y \equiv G + iB$. The subscript a is omitted when no confusion may arise.

From the definition of the complex frequency we have

$$|V(t)|^2 \approx |V_0|^2(1 + \rho) \qquad \rho = 4\pi \int \eta(t')\,dt' \quad (3)$$

where the integral is up to time t.

To go further, let us write down the carrier rate equation. dN/dt is the difference between the rate of carrier generation $J(t) \equiv J_0 + j(t)$, and the rate of carrier recombination. The latter is the optical power

$$P = G_a|V|^2/2 \quad (4)$$

generated in the mode by the active admittance, divided by the photon energy $h\nu_0$, if one assumes that the quantum efficiency is unity, and neglects spontaneous carrier recombination and the fluctuations associated with it. These latter terms are small when the operating current is much larger than the threshold current, but it would be easy to re-establish them if needed. Thus

$$d\,\delta N/dt = j(t) - R_0[\rho + (G_N/G)\,\delta N] \quad (5)$$

where R_0 denotes the average rate of carrier recombination. The rate eqns. 2–5 coincide with the usual rate equations only when $dG(\nu)/d\nu = 0$ at the operating point.

Let us now consider free relaxation oscillations, setting $j = 0$. The fluctuation ρ is readily found to obey the following second-order differential equation

$$d^2\rho/dt^2 + (R_0 G_N/G)\,d\rho/dt + 4\pi R_0\,\mathrm{Im}\,(Y_N/Y_\nu)\rho = 0 \quad (6)$$

where Im denotes imaginary part. The free-running relaxation oscillations can be characterised, as any damped oscillation, by a quality factor Q, which is, roughly speaking, the number of oscillations. From eqn. 6

$$Q^2 = 4\pi\,\mathrm{Im}\,(Y_N/Y_\nu)G^2/(R_0 G_N^2) \quad (7)$$

If we denote by Q_0 the value of Q when $G_\nu = 0$ (standard theory) we find

$$(Q/Q_0)^2 = (1 - \alpha h')/(1 + h'^2) \quad (8)$$

where

$$h' \equiv G_v/B_v > 0 \qquad \alpha \equiv B_N/G_N > 0 \quad (9)$$

I have, in Reference 7, identified $1 + h'^2$ with Petermann's K factor for lumped circuits. Eqn. 8 shows that even if K hardly exceeds unity the damping of relaxation oscillations relative to the relaxation period is much stronger than the one usually calculated. For example, if $\alpha = 5$, and $K = 1{\cdot}02$, a value that may be appropriate to CSP (channelled substrate planar) lasers that exhibit real but weak guidance in the junction plane, eqn. 8 predicts a value of Q/Q_0 as low as 0·55. Because there is also a K-factor in the longitudinal direction[8] eqn. 8 may be relevant to buried heterojunctions as well. Our result is in agreement with a result recently obtained by Gallion and Debarge.[9]

Only a single active-element circuit has been considered. It should be noted that even the simplest laser diode must be considered as an extended (or multielement) device because its dimensions are large compared with wavelength. For multi-element devices it is useful to rewrite eqn. 2 in the form

$$-2\pi i\, \delta\nu = V_1^2\, \delta Y_{a1} + V_2^2\, \delta Y_{a2} + \ldots \qquad (10)$$

where the subscripts 1, 2, ... refer to the active elements, and a phase and amplitude normalisation of the voltages has been introduced

$$\sum C_k V_k^2 - L_k I_k^2 = 1 \qquad (11)$$

where V_k is the voltage across all the capacitances C_k of the circuit, and I_k the current flowing though all the inductances L_k. This perturbation formula can be shown to be equivalent to a matrix generalisation of eqn. 2. A rate equation analogous to eqn. 5 can be written for each active element. However, it is not permissible to take the same ρ value for the different elements because the variations of V_1/V_2, for example, are of first order. These first-order variations do not matter in eqn. 10 which is variational, but they do matter in the carrier rate equations. The more difficult multielement problem will be discussed elsewhere.

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RECOVERY TIME FOR A SILICON WAVEGUIDE ALL-OPTICAL SWITCH

Indexing terms: Optical switching, Optical waveguides, Optical properties of substances

Dye laser pulses were used to switch the propagation path of an infra-red ($\lambda = 1{\cdot}3\,\mu m$) beam propagating in a planar silicon waveguide. Recovery times ranged from 1·2 to 15 ns, depend on both the pulsed laser wavelength and the illumination geometry.

Epitaxial silicon layers can be used effectively as optical waveguides at the important 1·3 and 1·55 μm optical communications wavelengths. In spite of the fact that silicon does not exhibit a linear electro-optic effect, there has been recent interest in its use for active integrated optical modulation and switching components. Such devices are based on the free carrier concentration dependence of the medium's refractive index and absorption coefficient. Soref and Lorenzo have carried out an analysis of silicon waveguides[1] and have demonstrated an electro-optic switch which uses a *pn*-junction to inject carriers into the intersection point of two optical waveguide channels.[2] Carrier injection can also be accomplished optically, using an intense pulse of light at a shorter wavelength where the silicon is strongly absorbing. All-optical logic gates have recently been developed using light pulses at a wavelength of 1·06 μm to control the transmission of an optical signal through a thin silicon slab.[3]

In this letter we report on an all-optical switching experiment in which the propagation path of a CW light beam in a planar silicon waveguide was controlled by an optical 'gate' pulse from a dye laser. The recovery time for the switch ranged from 1·2 to 15 ns and was found to depend on both the wavelength of the gate pulse and the illumination geometry.

The planar waveguides consisted of a 25 μm-thick, undoped silicon epilayer grown on a (111) oriented silicon substrate which was doped at a level of $5 \times 10^{18}\,cm^{-3}$. The refractive index difference between the substrate and epilayer was approximately 0·005[1] and thus the waveguides were highly multimode. Rectangular samples were cut and two opposite ends were mechanically polished to provide input and output faces. The beam from a CW diode laser, operating at $\lambda = 1{\cdot}3\,\mu m$, was then coupled into one of the ends using a 5× microscope objective lens. After propagating through a 4 mm long waveguide, the beam diverged to a half width of about 50 μm. The output light was collected with a multimode optical fibre and fed to a high-speed GaInAsP photodiode detector.

The optical gate pulses were generated by a nitrogen-laser-pumped dye laser system and were delivered to the silicon surface through a single mode optical fibre (8 μm core diameter). The end of the gate fibre was precisely positioned to illuminate the input face of the silicon waveguide, as indicated in Fig. 1. Alternatively the fibre could be oriented perpendicular to the waveguide plane so as to illuminate any spot along the propagation path of the 1·3 μm beam. In normal operation, the output fibre was positioned to maximise the throughput of the 1·3 μm signal.

When the 500 ps (FWHM) gate pulses were applied, in either geometry, the throughput was observed to drop abruptly and then recover within a few nanoseconds. This drop in the throughput is primarily due to the free-carrier-induced reduction in the refractive index which creates a diverging lens at the illuminated spot. A second, less important effect is free-

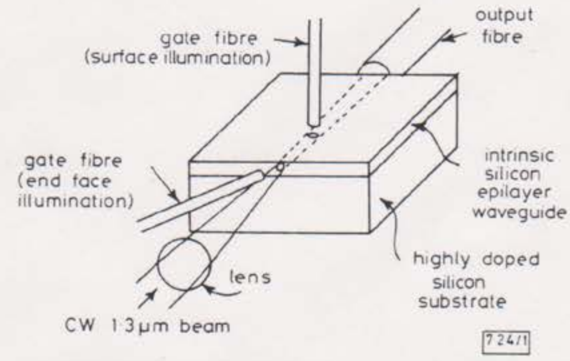

Fig. 1 *Experimental geometry, showing two possible orientations of optical gate fibre*