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The Response Time of High Pumped Short-Cavity Semiconductor Laser

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It is shown that electron-hole plasma reheating effect due to preferential eliminating of lower energy carriers of charge and intraband absorption of lasing leads to shoulders on the long wavelength picosecond pulses generated by short cavity semiconductor laser. The analytical expressions for pulse duration and plasma cooling time are obtained.

Over the past 10 years there has been a continued interest in studying the generation of picosecond pulses from semiconductor laser. The physical mechanisms which determine the pulse duration are still under consideration.

Most of theoretical results concerning the picosecond dynamics of the carriers of charge in semiconductor and photons in the optical cavity are obtained from a small signal analysis of laser rate equations - a procedure that linearizes the equations near the lasing threshold. The investigation of picosecond dynamics of high-speed semiconductor laser far above the threshold is very important to increase the power of lasing output. In the recent paper we consider theoretically the behaviour of optically pumped semiconductor laser as an example of laser operating far above the threshold. During the optical pumping high temperature electron-hole (e-h) plasma is generated. Under this conditions laser action in short-cavity semiconductor lasers has some peculiarities[1-2]:

1. Generation of λ - shaped short wavelength pulses.

2. Shoulders of the long wavelength pulses.

3. Time-varying wavelength (chirp) in the generated pulses.

In [1] the authors carrying out the numerical modeling of picosecond carriers and lasing dynamics in optically pumped semiconductor laser came to a conclusion that reheating of e-h plasma due to a preferential elimination of lower energy carriers could leads to shoulders on the long wavelength pulses. We have investigated the reheating effect numerically and analytically taking also into account the reheating of plasma due to intraband absorption of laser irradiation.

To describe the picosecond dynamics of lasing and of hot e-h plasma we have considered the equations which are a bookkeeping of the rate of supply, annihilation and creation of e-h pairs n, their energy W, and photons N_ω inside the laser cavity. For short-cavity semiconductor laser this equations become integro-differential due to the broadband nature of the semiconductor laser output:

$$\dot{n} = c \int \alpha(\omega)\, N_\omega\, d\omega, \tag{1}$$

$$\dot{W} = \alpha' B + c\int\alpha(\omega)(\hbar\omega-E'_g)N_\omega d\omega - nJ, \tag{2}$$

$$\dot{N}_\omega = (c\,\alpha(\omega) + \tau_p^{-1})\, N_\omega + g_\omega, \tag{3}$$

where c - the velocity of light in semiconductor, $\alpha(\omega)$ - the interband gain (absorption) coefficient of the light in semiconductor, α' - intraband absorption coefficient, $E'_g = E_g - n\,\partial E_g/\partial n$, E_g - the semiconductor band gap; $B = c\int \hbar\omega\, N_\omega\, d\omega$ - the intensity of light in the optical cavity, J - the rate of plasma cooling (per e-h pair) due to interaction of electrons and holes with optical phonones, τ_p - photon lifetime in optical cavity, g_ω - the rate of spontaneous irradiation.

We have solved this equations numerically with initial conditions $n = 5\cdot 10^{18}$ cm^{-3}, $T = 1200$ K, $T_L = 300$ K, $N_\omega = 0$, where T is the temperature of e-h plasma and T_L - lattice temperature. This initial conditions occur in experiments [1] due to optical pumping of semiconductor laser by intense subpicosecond pulse. For numerical solution we have used $\tau_p = 1$ ps, $\alpha' = \sigma n$, with $\sigma = 10^{-17}$ cm^2. Other parameters were chosen similar to those in GaAs. The results of numerical solution are shown in the Fig.1.

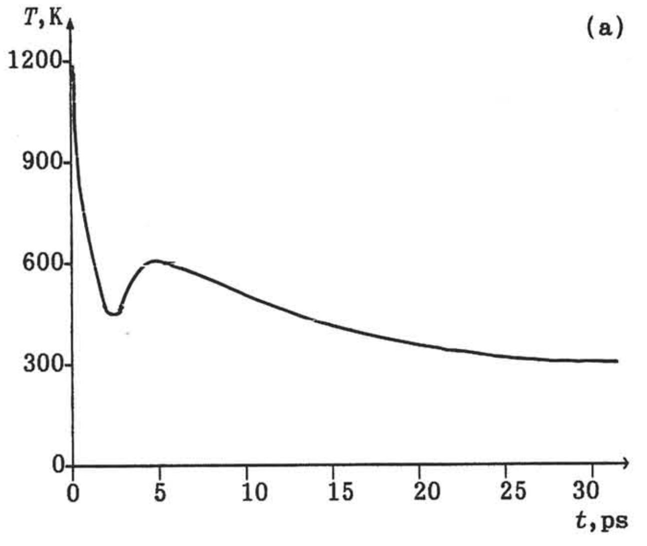
As it follows from the pictures there are two characteristic time scales in the dynamics of lasing and plasma cooling - "fast" and "slow". In this paper we have considered theoretically the "slow" dynamics which corresponds to the decay of long wavelength part of the spectrum. The analytical consideration of the equations is based on assumption that $\tau_p \ll \tau_T$, where τ_T - the characteristic plasma cooling time. We have shown that the rates of plasma cooling and damping of long wavelength lasing are determined by the same characteristic time τ_T. In the case $m_e \ll m_h$, $\tau_e \gg \tau_h$ (m_e, m_h - electron and hole effective masses, τ_e, τ_h - carrier-lattice energy relaxation times for electron and hole subsystems) and for high plasma temperature T when the distribution function of holes remains nondegenerate the τ_T can be find[3]:

$$\tau_T = (\beta_1 + \beta_2)\, \tau_h, \tag{4}$$

where $\beta_1 = \frac{5}{2}\left[\frac{\mathcal{F}_{3/2}(\eta_G)}{\mathcal{F}_{1/2}(\eta_G)} + 1\right]$ - describes reheating effect due to elimination of lower energy carries and $\beta_2 = \alpha' c\, \tau_p\, E_g/kT$ - due to intraband absorption of laser irradiation. $\mathcal{F}_i(\eta)$ - Fermi integrals, η_G can be found from the equation: $N_C\, \mathcal{F}_{1/2}(\eta_G) = N_V\, \mathcal{F}_{1/2}(-\eta_G)$, where N_C, N_V - densities of states in conductive and valence bands. For GaAs laser $\eta_G \approx 2$ and formula (4) reads:

$$\tau_T \approx (6.2 + 0.34\, \tau_p \sqrt{T}\; E_g)\, \tau_h,$$

where τ_T, τ_p and τ_h are measured in ps, T in K and E_g in eV. For $\tau_p = 1$ ps and $T = 500$ K we can find that $\tau_T \approx 16.6\tau_h$. According to[4] for $T = 500$ K, $T_L = 300$ K and concentration



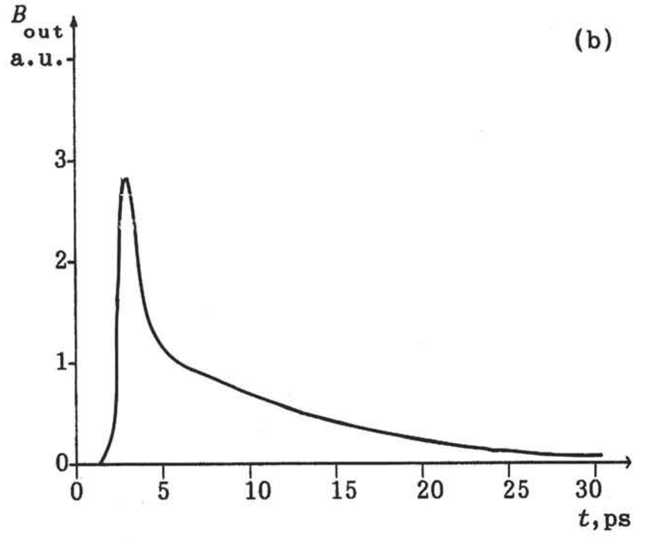


Fig 1. The dependence of plasma temperature 1(a) and laser output 1(b) on time, obtained from numerical solution of equation (1)-(3).

of carriers in GaAs $3\cdot 10^{18}$ cm^{-3} we have $\tau_h \approx 0.8$ ps and consequently $\tau_T \approx 13.2$ ps. This value is in a good agreement with experimental one[1-2]. It must be noted that in this case $\tau_T \gg \tau_h$, $\tau_T \gg \tau_p$ due to reheating effect and that β_1 and β_2 are of the same order. The lasing output as a function of plasma temperature can be found:

$$B_{out} = 3/4\; c\, E_g \frac{\tau_p}{\tau_T}\, n_G(T)\, \frac{T - T_L}{T} \ln(1/R),$$

where $n_G = N_C\, \mathcal{F}_{1/2}(\eta_G)$, R - mirror reflectivity. The change of T in time is ruled by the simple equation:

$$dT/dt = -\ (T - T_L)/\tau_T. \qquad (5)$$

As it follows from the equation (5) and can be seen from Fig. 1 the e-h plasma cooling rate considerably slowing down in the presence of stimulated emission. The results of numerical solution are in good qualitative and quantitative agreement with analytical predictions.

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