SELF MODULATION OF EMISSION FROM AN INJECTION SEMICONDUCTOR LASER

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The known existence of self modulation of the emission of optically-pumped lasers using ruby [1] or some other dielectric (called the "spike" mode) gives grounds for expecting similar phenomena in injection-type lasers, if we assume, following [2,3], that they exhibit the same self-oscillating properties of other lasers.

The kinetic equations for the power P of an injection semiconductor laser, per unit cross section of the active layer and for a normalized concentration S, can be written in the form

$$dP/d\theta = \alpha u\tau[(1 + \gamma)/(S_{th} - 1)][(S - S_{th})/(\gamma S + 1)]P, \qquad (1)$$

$$dS/d\theta = S_a - S - (S_a - S_{th})[(\gamma S_{th} + 1)/(S_{th} - 1)][(S - 1)/(\gamma S + 1)](P/P_0), \qquad (2)$$

where the coefficient of absorption of monochromatic light of frequency ν in a semiconductor with parabolic valence band and exponential conduction band is given [4] by the expression $\alpha_0 + \Psi = \alpha_0 + \Psi_0(1 - S)(1 + \gamma S)^{-1}$, with $S = (n - n_0)(n_s - n_0)^{-1}$, n the electron or hole density (assumed equal for both), n_0 the equilibrium density, n_s the density at which saturation (i.e., $\Psi = 0$) sets in for photons of energy $h\nu$, Ψ_0 and γ are positive constants, α_0 a damping coefficient characterizing all types of photon losses in the medium, α the effective damping coefficient which takes into account both α_0 and the loss to radiation from the resonator, $\theta = t/\tau$ the normalized time, τ the spontaneous recombination time, $S_{th} = (1 + \alpha/\Psi_0)(1 - \gamma\alpha/\Psi_0)^{-1}$ the threshold value of S, $P_0 = (1 - \alpha_0/\alpha)(S_a - S_{th})(n_s - n_0)(h\nu/\tau)L$, L the resonator length, $S_a = j\mu\tau[ed(n_s - n_0)]^{-1}$ the asymptotic value of S at P = 0 and $\theta \to \infty$, j the density of injection current in an active layer of thickness d, e the elementary charge, μ the injection quantum yield, and u the velocity of light in the medium. In (1) and (2) it is assumed that all the quantities have a uniform distribution in the active layer, that τ is independent of n, and that space-charge effects and traps can be neglected.

The system (1) and (2) with singularities at the points $S = S_{th}$, $P = P_0$ and $S = S_a$, $P = 0$ forms the phase picture typical of the spike mode, similar to that obtained in [3] for dielectric lasers with optical pumping.

If, as usual, $S = S_{th}(1 + \varphi)$ with $|\varphi| \ll 1$, then in a conservative approximation integration of (1) and (2) yields for the form of the spike near its peak

$$P/P_{sp} = 1 - A[(P_{sp} - P_0)^3/P_{sp}^2]\tanh^2\{[P_{sp}/P_0) - 1][(S_a/S_{th}) - 1]\theta\}, \qquad (3)$$

where

$$A = 2(S_a - S_{th})(\gamma S_{th} + 1)(S_{th} - 1)[\alpha u\tau S_{th}^2 P_0(\gamma + 1)]^{-1},$$

and for the ratio of the power at the minimum between the spikes, P_i, and at the maximum of the peak, P_{sp}, we get the relation

$$P_{sp} - P_i = P_0 \ln (P_{sp}/P_i).$$

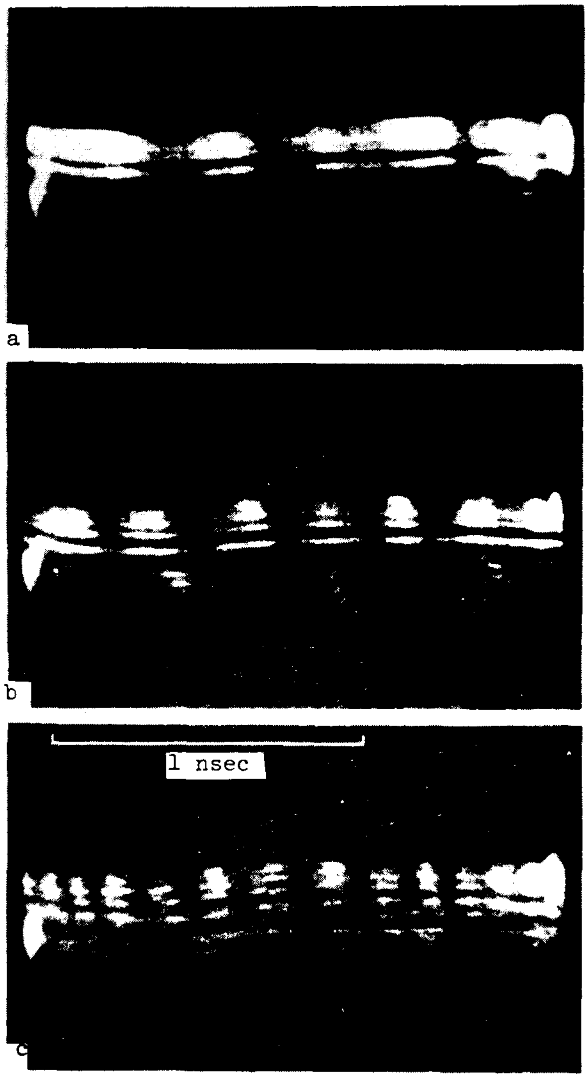
For the case $P_{sp} \gg P_0$, the spike duration θ_{sp} and the interval between them θ_i are estimated respectively at

$$\theta_{sp} \approx P_0 S_{th}[(S_a - S_{th})P_{sp}]^{-1} \ln \{[(2AP_0)^{1/2} + 1]/[(2AP_{sp})^{1/2} - 1]\}$$

and

$$\theta_i = 2S_{th}(S_a - S_{th})^{-1}(AP_{sp})^{1/2},$$

wherein, for typical values of the parameters, θ_{sp} and θ_i are essentially smaller than unity, a fact imposing stringent requirements on the time resolution of the apparatus for the registration of the radiation.



The time structure of the GaAs laser emission was observed experimentally with the aid of an electron-optical converter (EOC) [5] with a time-scanned image and with sweep duration ~2 nsec on a 35 mm screen, at a resolution not worse than 0.02 nsec. The time calibration was by two independent methods: with the aid of a 500 MHz sinusoidal voltage and by means of a 0.11-nsec optical delay of the split light signal. The image of the glowing active layer of the diode was projected by microscope objectives with magnification from 1× to 30× from a vacuum liquid-nitrogen cryostat onto the photocathode of the EOC in such a way that the plane of the p-n junction was perpendicular to the sweep direction. The GaAs diode with a p-n junction produced by diffusion was excited by single injection current pulses of 1 - 5 A and 600 nsec duration, synchronized with the pulsed supply to the EOC.

Typical photographs (see the figure) of the time-scanned image of the glowing active layer show clearly the emission self-modulation (spikes) (diode No. 63M4, threshold current 1.85 A). A decrease in the self-modulation period with increasing injection current is also noticed: 0.35 nsec at 2A, 0.21 nsec at

2.7 A, and 0.17 nsec at 4.3 A in Figs. 1a, 1b, and 1c, respectively. There was no self-modulation of the spontaneous emission below threshold (the brightness at different currents was equalized with light filters). Self-modulation periods of approximately 0.05 nsec were observed in other diodes with threefold excess over threshold. In addition to synchronous self-modulation of the emission from all the individual glowing regions of the active layer, as seen in the figure, non-synchronous modulation with unequal periods for different points were observed in diodes with sharply isolated glowing points, probably owing to the difference in their local thresholds and to the inhomogeneous distribution of the injection-current density.

It must be noted that the observed amplitude self-modulation with period shorter than 0.1 nsec may make an appreciable contribution to the line broadening of semiconductor lasers.

The calculation presented above was made essentially in the single-mode approximation. Therefore to compare the calculated and experimental data it is necessary to supplement the latter with spectral measurements, which permit an estimate of the mode content in the emission. The time-dependent characteristics themselves should be subjected to a microphotometric analysis. Even now, however, we can already note that the calculated and experimental values of the self-modulation period as a function of the injection current level agree in order of magnitude.

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USE OF ARTIFICIAL METEORS FOR LASER PUMPING

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Recent papers [1,2] report the use of the energy of an explosion or a flame jet for laser pumping. In these investigations the pump light flash was produced either by magnetohydrodynamically obtained electric energy, or by the glow of gas in an explosion shock wave [2].

We discuss in this paper certain possibilities of using artificial meteors, or rapidly moving objects accelerated by gunshot, to pump medium-power lasers.