Semiconductor saturable absorber model with circuitry

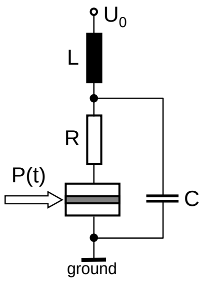
ede
(Dated: January 21, 2004)

I. PROBLEM DESCRIPTION

A short semiconductor section negatively biased with $U_0 < 0$ is often used as a saturable absorber. A pulse train $P(t)$ is injected causing an ac photocurrent. In order to model the behavior of the absorber under these conditions, its series resistivity R, wire inductivity L, and parasitic capacity C have to be considered.

II. MODEL COMPONENTS

I use the following circuit schema of semiconductor lasers, as given in the Petermann-Book.



The basic voltage-current relations of a resistivity, inductivity, and capacity are

$$U_R = RI_R, \quad U_L = L\dot{I}_L, \quad \text{and} \quad C\dot{U}_C = I_C, \tag{1}$$

respectively. The intrinsic voltage-current relation of the semiconductor absorber can be modeled by the Fermi voltage

$$U_F(N) = U_g + U_T \ln\left(\frac{N}{n_t}\right), \quad eU_g = E_g, \quad eU_T = kT, \tag{2}$$

with temperature T, Boltzmann constant k, band gap E_g of the active layer, transparency concentration n_t. This simple logarithmic Boltzmann law is valid as long as N does not exceed n_t, which holds in the absorber regime of operation (but no more when operating the device as a laser). Furthermore, it has been used the reasonable assumption that $U_F = U_g$ holds at transparency.

The Fermi voltage depends on the excess carrier density, which in turn obeys the rate equation

$$\dot{N} = \frac{I}{eV} - r(N) - G(N)S(t). \tag{3}$$

I: injection current (positive in forward direction), V: volume of the active layer, $r(N)$: nonstimulated recombination rate, $G(N)$: gain function (per unit time), $S(t) \sim P(t)$: average photon density in the active layer. The recombination rate can be modeled by

$$r(N) = \frac{N - n_i}{\tau}, \quad \text{with } n_i = n_t \exp\left(-\frac{U_g}{U_T}\right) \tag{4}$$

being the intrinsic concentration of the active material. The n_i-contribution to r is usually neglected in lasers, because it is extremely small. When operating with reverse voltage, however, N can become even smaller, in which case this contribution gives the saturation value of the reverse dark current

$$I_s = \frac{eVn_i}{\tau}. \tag{5}$$

For the gain function, the logarithmic model

$$G(N) = G' n_t \ln\left(\frac{N}{n_t}\right) \sim U_F(N) - U_g \tag{6}$$

seems to be more reasonable than the linear one, because it provides the very high absorption values at reverse voltages $U_F < 0$.

III. FULL MODEL

Applying Kirchhoff's fundamental node and mash laws to the given quasistationary[1] electrical circuit, all the given model components can be combined. When using those quantities as dynamical variables whose derivatives appear in Eqs. (1) and (3), one arrives at

$$\dot{N} = \frac{I}{eV} - r(N) - G(N)S(t), \qquad I = \frac{U_C - U_F(N)}{R} \tag{7}$$

$$\dot{U}_C = \frac{I_L - I}{C}, \tag{8}$$

$$\dot{I}_L = \frac{U_0 - U_C}{L}. \tag{9}$$

In my opinion, this is the appropriate model for a short semiconductor saturable absorber. Before a further general discussion or application, I need typical values for the parameters C, L. I know only $R \approx 2\Omega$mm/length.

---

[1] radiation losses neglected