Impact of the Purcell and Spontaneous Emission Factors in Nanowire Lasers

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Abstract In this paper, we present a numerical estimation of spontaneous emission factor for nanowire lasers and, investigate the impact of Purcell effect $F$ and spontaneous emission factor $\beta$ on the threshold and the L-L curves. Theoretical calculations provide more insights into the laser behaviour as they predict spontaneous emission coupling efficiency before fabrication and are helpful to optimise the cavity [1].

Results and discussion The rate equations for nanowire lasers are written as:

$$\frac{dN}{dt} = \frac{\eta P}{h f V} - \frac{(1 - \beta_0)N}{t_{sp}} - \frac{F \beta_0 N}{t_{sp}}$$

$$\frac{dS}{dt} = \Gamma \frac{F \beta_0 N}{t_{sp}} + \Gamma g S - \frac{S}{t_p}$$

$F = \frac{3}{4\pi^2} \left( \frac{\lambda}{n} \right)^3 \left( \frac{Q}{V} \right)$ is the Purcell factor [2]. $\beta$ and $\beta_0$ are spontaneous emission factors with and without Purcell effect, respectively and, are related as $\beta = \frac{F \beta_0}{1 + (F - 1) \beta_0}$. $\beta$ is usually treated as a fitting parameter shaping the height of the kink in the L-L curves. However, we propose $\beta \approx \frac{\lambda^3 L_z}{2\pi^2 V \Delta \lambda n^2}$ for multiple quantum disks embedded in nanowire lasers. $\Delta \lambda$ is spontaneous emission linewidth, $V$ is the Volume, and $L_z$ is the thickness of the gain medium. $\beta$ is calculated with the same approach as [3] using the ratio between spontaneous emission rate into the lasing mode to the total spontaneous emission rate. For the nanowire laser in [4], we calculate the threshold to be around $1.6 \mu J cm^{-2}$, $F \approx 26.17$, and $\beta \approx 0.1$. This agrees with experimental results. Solving (1) for different values of Purcell factors ranging from 26 to 1 shows that lower dimensions of nanowire result in higher $F$ which decreases the threshold non-linearly as shown in Figure 1a. Meanwhile, higher $F$ provides more spontaneous emissions to couple into the lasing mode making less pronounced kinks as $\beta$ gets closer to unity in Figure 1b.

Figure 1. a) Impact of the Purcell factor, b) Impact of spontaneous emission factor