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Output characteristics of superluminecent light emitting diodes used in optic fiber gyroscope

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ABSTRACT

In this paper, we have pointed out the mathematical model of SLED output power with drive current and cavity length. It is observed that the mean wavelength decreases with the increasing drive current, the extinction ratio increases with the increasing drive current. Furthermore, the output power decreases with the increasing temperature, the mean wavelength increases linearly with the increasing temperature.

1. Introduction

Superluminescent light emitting diodes (SLEDs) are edge-emitting semiconductor devices with an optical waveguide that emit spectrally broad amplified spontaneous emission (ASE) with an arrow emission angle, SLEDs are a light source with properties intermediate between those of a light-emitting diode (LED) and laser diode (LD). Due to their broad emission spectra and high power, SLEDs are available for use in fiber optical current sensor [1], fiber optic gyroscope [2] and optical coherence tomography [3]. The SLEDs output characteristics depend on the drive current and temperature, SLEDs maintain drive current stable with a constant current, in order to stabilize the power, spectral and polarization parameters of radiation and to increase the reliability of the devices, SLED in light-emitting modules are usually mounted on a TEC cooler which can maintain the temperature of the diodes at a constant level (usually 25 °C). At present, the research on output characteristics of SLED are mostly in the experimental stage, theoretical studies are not complete. In this paper, a relatively simple analytical model is derived for the accurate description of an SLED's *P–I* characteristic, and the main output parameters and performances under different drive current and temperature are given in experiments, including the output power, wavelength and polarization Finally, a summary of our results is made in the conclusion part.

2. Output power

The SLED light-emitting mechanism is shown in Fig. 1. The holes from the P layer and the electronics from N layer composite and luminescent in the active region under the current injection conditions. The reflection of two surfaces will cause laser oscillations, which can lead to spectrum width narrowing, therefore, it need to reduce surface reflections, usually there are several techniques to achieve including utilizing AR, tilted, bent or trapped waveguides, buried facets and integrated absorption regions [4].

We neglect the longitudinal spatial hole burning effect. In one-dimensional model, the optical wave propagation along the SLED cavity can be described by the following wave equation [5]:

$$v_g^{-1} \times \frac{dE_{f,b}(z,t)}{dt} \pm \frac{dE_{f,b}(z,t)}{dz} = \left[\frac{1}{2}(\Gamma g_m - \alpha_m) \mp j\beta_m\right] E_{f,b}(z,t) + S_{f,b}(z,t) \quad (1)$$

where v_g is the group velocity, $E_{f,b}(z,t)$ represents light field intensity of forward and backward traveling optical waves, Γ is the confinement factor, g_m is the material gain, α_m is the mode loss, β_m is the polarized light propagation constant, $S_{f,b}(z,t)$ represents the spontaneous emission field.

The spontaneous emission field of single direction polarized light which is coupled to waveguide is given as [6]:

$$S_{f,b}(z,t) \times \Delta z \Delta v = \Gamma g_m n_{sp} h v \Delta z \Delta v \quad (2)$$

where n_{sp} is the inversion factor, hv is the single photon energy.

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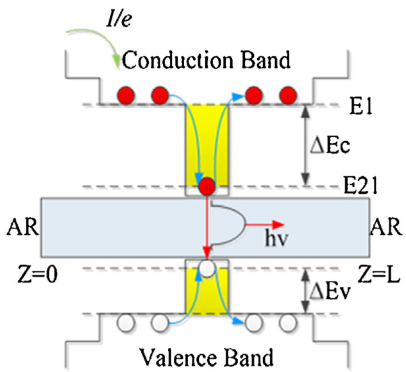

Fig. 1. The SLED light-emitting mechanism.

At the steady state, $\left(\left(dE_{f,b}(z,t)\right)/dt\right) = 0$, the power $P_m(z) = hv\left|E_{f,b}(z,t)\right|^2$. The forward and backward-propagated waves are symmetrical and can be expressed by the same equation. The formula (1) is the differential equation of optical field in z direction. If we assume the gain is uniform in longitudinal and the spectral energy density of SLED is relatively low compared to laser diodes, we neglect the gain saturation effect. Based on boundary condition $P_m(z=0) = 0$, the expression for total output power can be obtained from (1):

$$P = \sum_m 2n_{sp}hv^2 \times \frac{\Gamma g_m}{\Gamma g_m - \alpha_m} \times e^{(\Gamma g_m - \alpha_m)L} \tag{3}$$

In order to simplify the analysis, we make some assumptions for rate equation: there is only one oscillation mode in resonant cavity; neglecting the impact of non-radiation recombination and the lateral diffusion of carriers. The coupling rate equation for carrier density n and single mode photon density s can be described as [7]:

$$\frac{dn}{dt} = \frac{J}{qd} - \frac{n}{\tau_{sp}} - R_{st}s \tag{4}$$

$$\frac{ds}{dt} = R_{st}s + \frac{n}{\tau_{sp}} - \frac{s}{\tau_{ph}} \tag{5}$$

where J is the current injection density, $J = I/L$, d is the active region thickness, τ_{sp} is the carrier lifetime, τ_{ph} is the photon lifetime, R_{st} is the stimulated emission rate, $R_{st} = v_g \Gamma g_m$. At the steady state, $\left(dn/dt\right) = 0$, $\left(ds/dt\right) = 0$, when the current density reaches the threshold current density, the number of photons is approximately zero, we can get the threshold current density J_{th}:

$$J_{th} = \frac{qdn_{th}}{\tau_{sp}} \tag{6}$$

where n_{th} is the carrier density when injection current reaches the threshold value.

We suppose the SLED gain is:

$$g_m \approx a(n - n_{th}) \approx \frac{(J - J_{th})}{\Gamma J \tau_{ph} v_g} \tag{7}$$

where a is the differential gain coefficient and we neglected qd due to its value is very small compared with $\Gamma J \tau_{ph} v_g$. Fig. 2 shows the modal gain curve versus injection current density.

According to formula (2) and (6) above, the relationship between output power and drive current can be expressed as:

$$P = P_0 \times e^{-\alpha_0 L} \times e^{K \times [(I - I_{th})/I] \times L} \tag{8}$$

where $P_0 = n_{eff} \times 2n_{sp}hv^2 \times \left(\Gamma g_0/\Gamma g_0 - \alpha_0\right)$, $K = \left(1/\tau_{ph}v_g\right)$. In Table 1, all constants and parameters are used for following simulation and comparison.

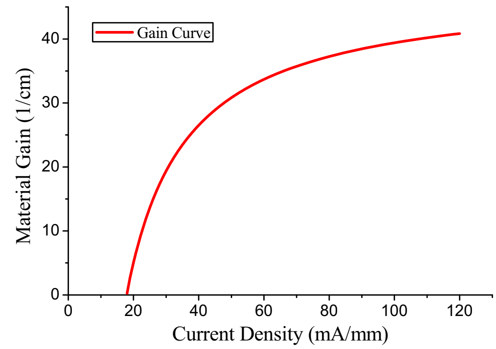

Fig. 2. Modal gain versus injection current density.

Table 1
Constants and parameters.

Parameter	Symbol	Value
Confinement factor	Γ	0.45
Photon lifetime	τ_{ph}	2.5 ps
Inversion factor	n_{sp}	1.0
Effective relevant coefficient	n_{eff}	402
Highest gain coefficient	g_0	40.2/cm
Mode loss	α_0	6.0/cm
Threshold current density	J_{th}	17.9 mA m
Effective group index	n_g	3.56

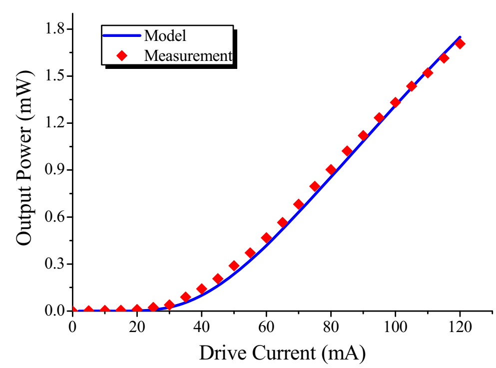

Fig. 3. Comparison between measured and theoretical *P–I* characteristics.

The SLED output power is the sum of all modes energy, where the mode energy with the highest gain accounts for about half of total energy, the total output power can be described by the highest gain coefficient $g_0(\lambda = \lambda_0)$ and effective coefficient of relevant mode n_{eff}. The relationship between output power and drive current can be expressed as:

$$P = P_0 \times e^{-\alpha_0 L} \times e^{K(I - I_{th}/I)L} \tag{9}$$

where I is drive current, I_{th} is threshold current, the comparison between measured *P–I* characteristics and curves computed from the analytical Eq. (8) are shown in Fig. 3. The experimental results are consistent with the theoretical model.

SLEDs convert most of the electrical power into light power, as well as parts of the electric power are converted into heat in the junction area and make the junction temperature increase, which lead to changes of threshold current subsequently. The relationship between threshold current and temperature is given as [8]:

$$I_{th} = I_{th0} \exp\left(\frac{T}{T_0} - 1\right) \tag{10}$$

where I_{th0} is the threshold current at T_0. Fig. 4 shows that the output power decreases with increasing temperature for a constant injection current.