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Measurement of the Thermal Impedance of Injection Lasers

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The method of determining the thermal resistance of injection lasers by a null measurement employing the thermal drift of a single Fabry-Perot wavelength is extended to yield the thermal time constant and thermal capacitance of an equivalent circuit. Thermal resistances of 52 K/W and thermal time constants of 2.6 µs are reported for DH-structures with stripe-geometry.

Messung der thermischen Impedanz von Injektionslasern

Der Realteil der thermischen Impedanz von Injektionslasern kann durch Nullabgleich der thermischen Verschiebung eines Fabry-Perot-Modus bestimmt werden. In Erweiterung dieses Verfahrens wird eine Methode zur Messung der thermischen Zeitkonstante und thermischen Kapazität des Wärmeersatzschaltbildes angegeben. An DH-Lasern mit Streifenkontakt wurden thermische Widerstände von 52 K/W und thermische Zeitkonstanten von 2,6 µs gemessen.

The thermal behaviour of injection lasers including their thermal response to transients in heatsink temperature or dissipated electrical power can be described by the simple equivalent circuit of Fig. 1. N represents the heat input power to the device, R_{th} the thermal resistance, C_{th} the thermal capacitance, and $\Delta T = T_{\mathrm{D}} - T_{\mathrm{H}}$ the difference of device temperature T_{D} and heatsink temperature T_{H}.

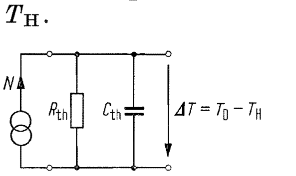

Fig. 1. Thermal equivalent circuit of an injection laser; N: heat power, T_{D}: temperature of laser device, T_{H}: temperature of heatsink.

Since the refractive index of an injection laser resonator depends on temperature [1], the wavelength of a single Fabry-Perot mode will vary with temperature, too. If the resonator temperature is raised by an increment ΔI of the injection current, the observed mode will shift to higher wavelengths. Simultaneously lowering the heatsink temperature by ΔT_{H} compensates the wavelength shift. Provided this null condition holds the resonator temperature has remained constant. The influence of free carriers on the refractive index [2] has been neglected. The drop ΔT_{H} of the heatsink temperature corresponds to the increase $\Delta T_{\mathrm{D}} = -\Delta T_{\mathrm{H}}$ of the resonator temperature caused by an additional dissipated electrical power $\Delta N = U \Delta I$, where U stands for the (nearly constant) device voltage. This procedure [3] leads to the thermal resistance $R_{\mathrm{th}} = \Delta T_{\mathrm{D}}/\Delta N$. The emitted radiative power is assumed to be a negligible fraction of the electrical input power.

To complete the equivalent circuit of Fig. 1 the thermal time constant $\tau_{\mathrm{th}} = R_{\mathrm{th}} C_{\mathrm{th}}$ has to be determined. Given a dc injection current I and a constant heatsink temperature T_{H}, a certain resonator mode $\lambda_{\mathrm{M}} = \lambda_1$ is selected by a diffraction grating monochromator of half-power bandwidth (HPBW) $\delta\lambda$. At time $t = 0$ a step function of height ΔI is superimposed to the dc current, resulting in a monochromator light output power $P_{\lambda_1, \delta\lambda}$ as recorded in Fig. 3. The current step is answered by a corresponding light power step of the resonator mode λ_1 within the bandwidth $\delta\lambda$. Immediately afterwards the resonator temperature T_1 rises exponentially towards temperature T_2 and the wavelength shifts to $\lambda_2 = \lambda_1 + \Delta\lambda$. Therefore the light power $P_{\lambda_1, \delta\lambda}$ decreases exponentially, if a linear relationship between temperature and wavelength is assumed and if the transfer function of the monochromator can be approximated by a triangle, Fig. 2. With these assumptions the relative light output power of the monochromator reads

$$L_{\lambda_1, \delta\lambda}(t > 0) = \frac{P_{\lambda_1, \delta\lambda}(t > 0)}{P_{\lambda_1, \delta\lambda}(+0)} = \\ = 1 - \frac{\Delta\lambda}{\delta\lambda}\left[1 - \exp(-t/\tau_{\mathrm{th}})\right], \qquad (1)$$

when $\Delta\lambda \leqq \delta\lambda$. If $\Delta\lambda > \delta\lambda$, then eq. (1) holds for $t \leqq t_1 = \tau_{\mathrm{th}} \ln \dfrac{\Delta\lambda}{\Delta\lambda - \delta\lambda}$, otherwise $L_{\lambda_1, \delta\lambda}(t) = 0$.

The thermal time constant τ_{th} can be determined from the slope of $L_{\lambda_1, \delta\lambda}(t)$ at $t = 0$,

$$\tau_{\mathrm{th}} = -\frac{\Delta\lambda}{\delta\lambda}\left[\frac{\mathrm{d}L_{\lambda_1, \delta\lambda}(t = 0)}{\mathrm{d}t}\right]^{-1}. \qquad (2)$$

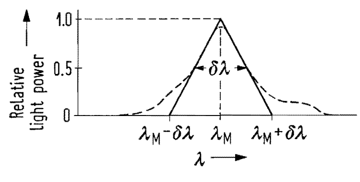

Fig. 2. Transfer function of diffraction grating monochromator with equal entrance and exit slits; —— idealized, ---- practical.

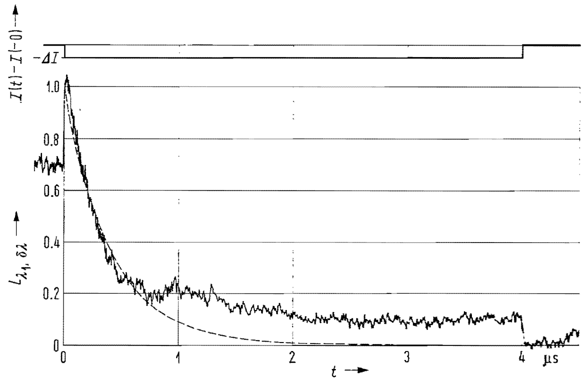

Fig. 3. Normalized light power $P_{\lambda_1, \delta\lambda}(t) = L_{\lambda_1, \delta\lambda}(t)\, P_{\lambda_1, \delta\lambda}(+0)$ at the wavelength λ_1 in the HPBW $\delta\lambda$ and injection current I; —— measured, ---- fitted exponential function, $\Delta I = 10$ mA, $I < 0$.

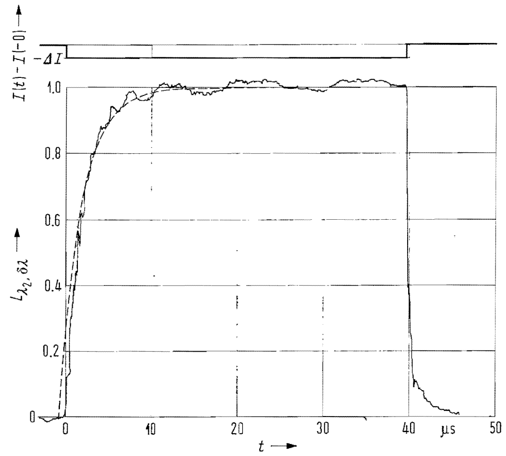

Fig. 4. Normalized light power

$$P_{\lambda_2,\delta\lambda}(t) = L_{\lambda_2,\delta\lambda}(t)\,P_{\lambda_2,\delta\lambda}(\infty) + P_{\lambda_2,\delta\lambda}(-0)$$

at the wavelength λ_2 in the HPBW $\delta\lambda$ and injection current I; —— measured, ---- fitted exponential function, $\Delta I = 10$ mA, $I < 0$.

If the power $P_{\lambda_2,\delta\lambda}$ at the wavelength $\lambda_M = \lambda_2$ is measured, an exponential rise as shown in Fig. 4 can be observed. The functional dependence follows

$$L_{\lambda_2,\delta\lambda}(t > 0, t_2) = \frac{P_{\lambda_2,\delta\lambda}(t > 0, t_2) - P_{\lambda_2,\delta\lambda}(-0)}{P_{\lambda_2,\delta\lambda}(t \to \infty)} = 1 - \frac{\Delta\lambda}{\delta\lambda}\exp(-t/\tau_{th}) \qquad (3)$$

with $t_2 = \tau_{th}\ln(\Delta\lambda/\delta\lambda)$. If $\Delta\lambda < \delta\lambda$, i.e. if the wavelength λ_1 lies inside the triangular transfer function of the monochromator, an initial jump of intensity from zero to $L_{\lambda_2,\delta\lambda}(+0) = 1 - (\Delta\lambda/\delta\lambda)$ occurs.

The thermal time constant τ_{th} can be determined from the slope of $L_{\lambda_2,\delta\lambda}(t)$ (extrapolated, if $t_2 < 0$) at $t = t_2$,

$$\tau_{th} = \left[\frac{\mathrm{d}L_{\lambda_2,\delta\lambda}(t = t_2)}{\mathrm{d}t}\right]^{-1}, \qquad (4)$$

and is seen to be measured without knowledge of $\Delta\lambda$ and $\delta\lambda$, as is necessary with eq. (2).

The investigated lasers had a DH-structure with stripe-geometry (recombination volume 0.5 µm × 17 µm × 500 µm) and a threshold current of typically 170 mA. They were mounted on a diamond heatsink soldered to a copper stud.

As described above the thermal resistance R_{th} was measured with a monochromator HPBW of $\delta\lambda = 0.1$ Å at heatsink temperatures of $T_H = 10$, 20, 30, 40 °C. Injection current changes of $\Delta I \approx \pm 10$ mA, corresponding to an electrical power change of $\Delta N \approx \pm 20$ mW at a device voltage of $U \approx 2$ V, caused a shift of the laser wavelength which was nulled by a heatsink temperature change of $\Delta T_H = \mp 1$ K. A typical result of the evaluation is $R_{th} = 52.3$, 47.5, 58.2, 51.2 K/W at the respective heatsink temperatures. No significant temperature dependence could be observed. The average value of $R_{th} = 52$ K/W was used for further computation.

For measuring the thermal time constant from the slope of $L_{\lambda_1,\delta\lambda}(t = 0)$, eq. (2), the monochromator HPBW $\delta\lambda$ and the stationary wavelength shift $\Delta\lambda$ must be known. $\delta\lambda = 0.1$ Å is determined from the known dispersion of the grating in the slit plane (assuming equal exit and entrance slits) and from the calibrated slit width. $\Delta\lambda$ should be measured by the monochromator, too, with the stationary currents I for λ_1 and $I + \Delta I$ for $\lambda_2 = \lambda_1 + \Delta\lambda$. Unfortunately the available instrument permitted no calibrated manual depositioning of the midband wavelength λ_M in the order of $\delta\lambda$. On the other hand a larger wavelength shift $\Delta\lambda$ caused by a greater current step ΔI could not be tolerated, for the relative intensity distribution of the lasing modes must not be disturbed, otherwise a large error in measuring τ_{th} from $L_{\lambda_1,\delta\lambda}$ (and $L_{\lambda_2,\delta\lambda}$) is introduced. So $\Delta\lambda = 0.7$ Å was calculated, using the measured data of the thermal resistance R_{th}, the change in electrical power $\Delta N = 26$ mW, and the measured shift of a resonator mode with temperature $c_\lambda = 0.55$ Å/K. A calculation of c_λ [1] yields similar values. Thermal changes of the resonator geometry usually have an influence, which is an order of magnitude smaller than the influence of the temperature dependent refractive index. The recorded $L_{\lambda_1,\delta\lambda}(t)$ together with the injection current change $I(t) - I(-0)$ are shown in Fig. 3. An exponential fit yields $[\mathrm{d}L_{\lambda_1,\delta\lambda}(t = 0)/\mathrm{d}t]^{-1} = 0.41$ µs, therefore $\tau_{th} = 2.9$ µs and $C_{th} = 56$ nWs/K.

Deviations from the exponential function are observed because of deviations of the monochromator transfer function at low HPBW $\delta\lambda$ from the idealized linear function, Fig. 2. Firstly the top of the transfer function will be flat, therefore the recorded $L_{\lambda_1,\delta\lambda}(t)$ at $t = 0$ is not as sharp-edged as the fitted exponential. Secondly the wings of the transfer function will extend beyond $\lambda_1 \pm \delta\lambda$ to about $\lambda_1 \pm \Delta\lambda$, therefore the recorded $L_{\lambda_1,\delta\lambda}(t)$ with $t \to \infty$ will not approach zero.

Measuring the thermal time constant from the slope of $L_{\lambda_2,\delta\lambda}(t = t_2)$ is a more comfortable and accurate method, but it relies upon linearity of the monochromator transfer function, too, so the above mentioned limitations have to be observed. Again an exponential fit gives $\tau_{th} = 2.6$ µs and $C_{th} = 50$ nWs/K, which agrees well with the time constant derived from eq. (2), the error being about 12%. Theoretical calculations of the thermal time constant [4] are confirmed by these measurements.

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References

[1] Marple, D. T. F., Refractive index of GaAs. J. appl. Phys. **35** [1964], 1241–1242.

[2] Shore, K. A. and Adams, M. J., Theory of the double heterostructure laser: II. Waveguide model incorporating carrier concentration-dependent refractive index. Opt. Quant. Elect. 8 [1976], 373–381.

[3] Paoli, T. L., A new technique for measuring the thermal impedance of junction lasers. Transact. Inst. Elect. Electron. Engrs. QE-**11** [1975], 498–503.

[4] Maslowski, S., AEG-Telefunken: private communication.