

Diode Laser Parameters and Characteristics

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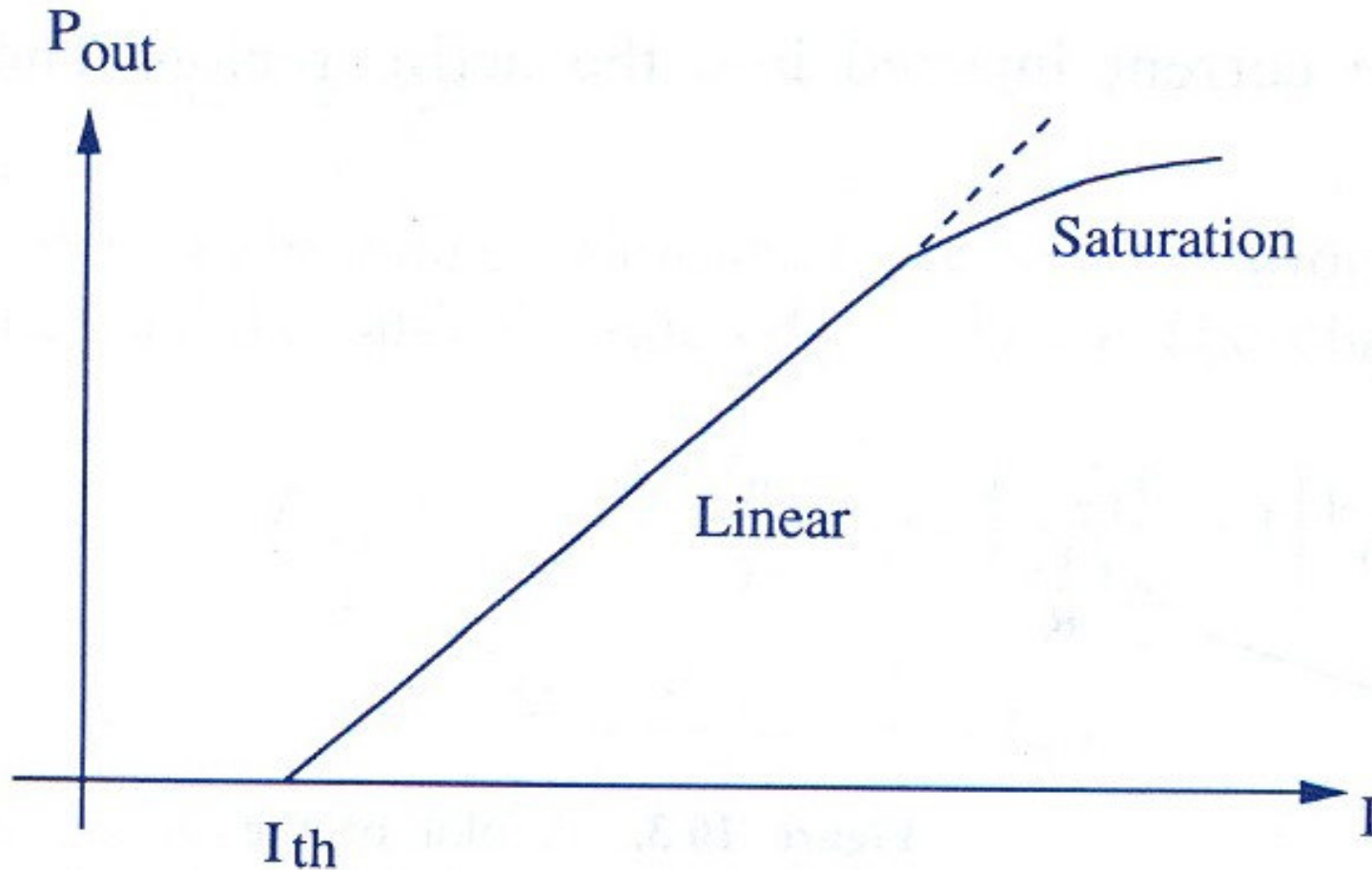
P-I Curve and Related Parameters

The output optical power P_{out} vs. the injection current I can be modified to be

$$P_{out} = \frac{\hbar\omega}{q} \frac{\alpha_m}{\alpha_m + \alpha_i} \eta_i (I - I_{th} - \Delta I_L)$$

where ΔI_L accounts for any additional increase in the leakage current due to the increase of I , α_i is the intrinsic loss, α_m accounts for the transmissions at two end mirrors (facets).

The typical output power vs. injection current relation



A typical diode laser output power vs. injection current density relation

η_i is the internal quantum efficiency, which is defined as the percentage of the injected carriers that contribute to the radiative recombinations

The external differential quantum efficiency η_e is defined as:

$$\eta_e = \frac{dP_{out} / dI}{\hbar \omega / q} = \eta_i \frac{\alpha_m}{\alpha_m + \alpha_i}$$

Below the threshold injection current, the output light intensity is negligibly small.

Above threshold, the output power is linearly increasing until saturation effects occur.



possible reasons for saturation saturation:

1. The leakage current increases with the injection current.
2. The threshold current may also depend on the injection current due to junction heating. The increase in temperature reduces the recombination lifetime.
3. The internal absorption increases with an increase in the injection current.

G-Energy (Wavelength) Curve and Related Parameters

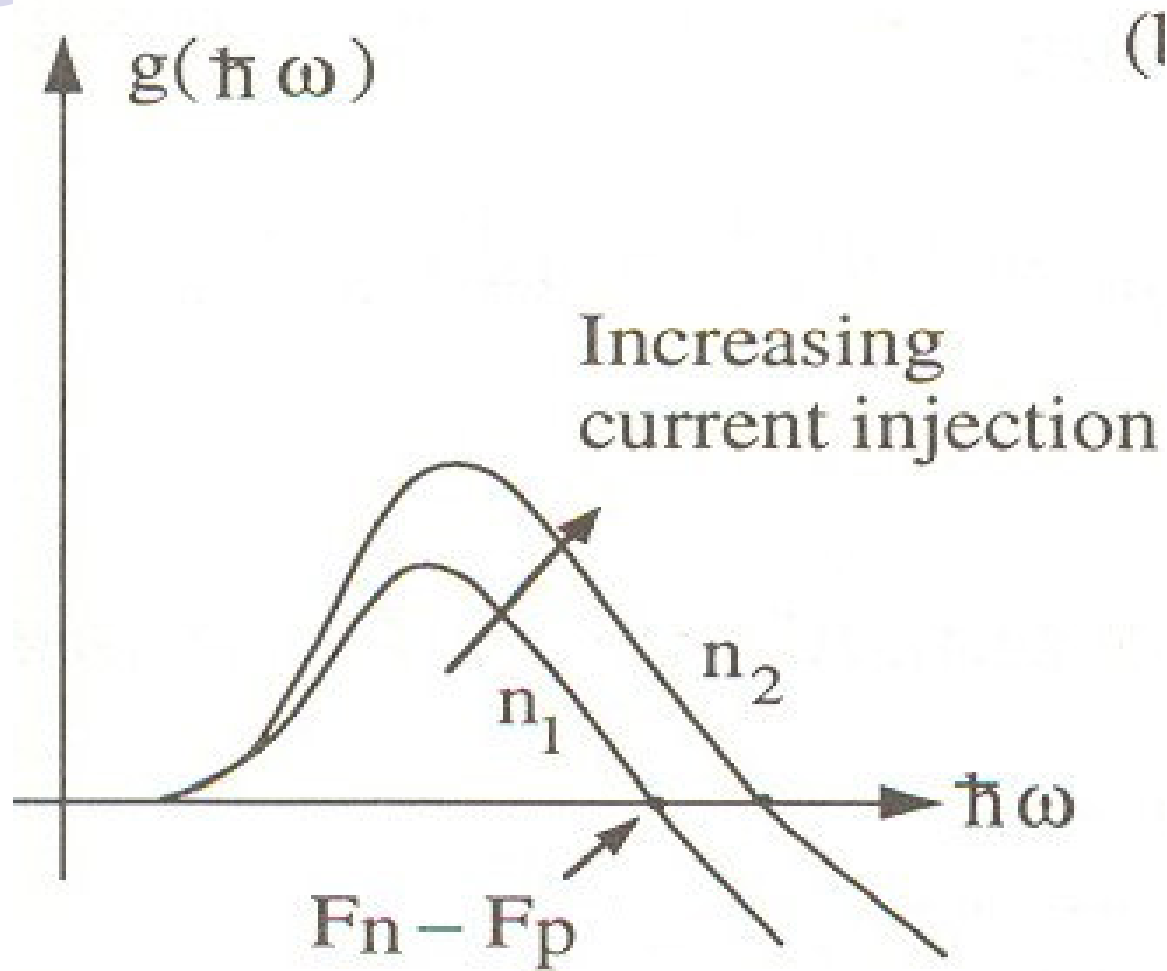
Finite-Temperature Gain Spectrum

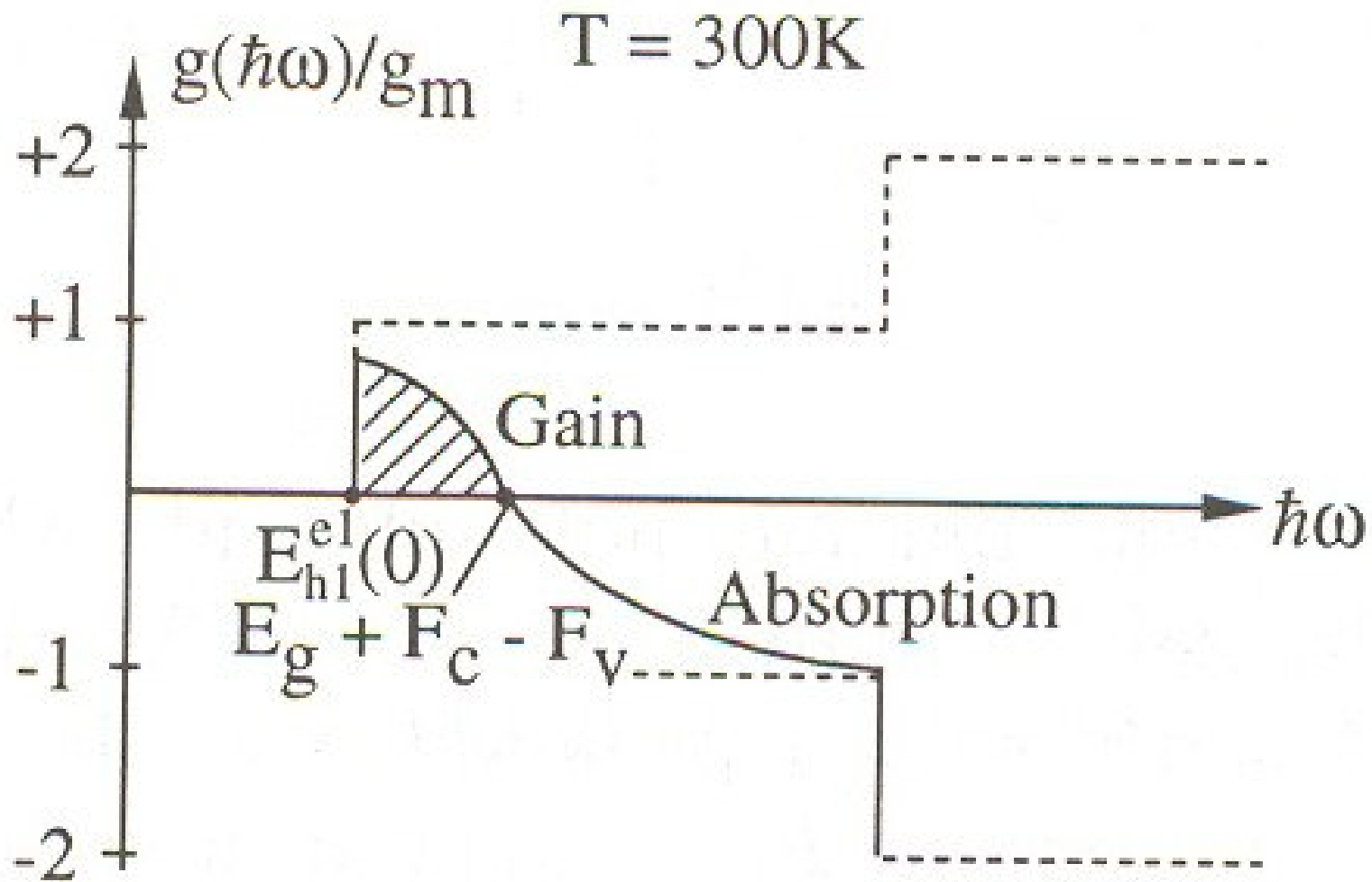
It is given by Eq.

$$g(\hbar\omega) = \sum_{n,m} g_m [f_c^n (E_t = \hbar\omega - E_{hm}^{en}) - f_c^m (E_t = \hbar\omega - E_{hm}^{en})] H(\hbar\omega - E_{hm}^{en})$$

Gain occurs when $f_c^n > f_c^m$

Finite Temperature Gain Spectrum





Description of Gain Spectrum

In the figure, it starts with a peak value at the transition edge $\hbar\omega = E_{h1}^{e1}(0) = E_g + E_{e1} - E_{h1}$ where $E_t = 0$, and decreases to zero at $E_g + F_c - F_v$ then becomes absorption at higher optical energies.

The sharp rise in gain near the band edge compared with the soft increase in a bulk(3D) semiconductor is due to the steplike density of states in 2D vs. the slow increase of the square-root(\sqrt{E}) density of states in 3D.

The Fermi-Dirac distribution will deviate from a sharp step function and is equal to $1/2$ at the quasi-Fermi level.

The hole concentration is

$$p = \sum_{m=1}^{\infty} n_v \ln(1 + e^{(E_{hm} - F_v) / k_B T})$$

where

$$n_v = \frac{m_h^* k_B T}{\pi \hbar^2 L_z}$$

which can account for heavy-hole and light-hole subbands, where m accounts for hole subbands.

G-J Curve and Related Parameters

For a quantum-well laser lasing from only the first quantized electron and hole subbands, we use the empirical logarithmic formula for the peak gain-current density relation

$$g_w(J) = g_0 \left(1 + \ln \frac{J_w}{J_0}\right)$$

where J_w and g_w are the injected current density and the peak gain coefficient of a single-quantum-well (SQW) structure.

The transparency current density occurs at $J_{tr} = J_0 e^{-1}$

G-J Curve

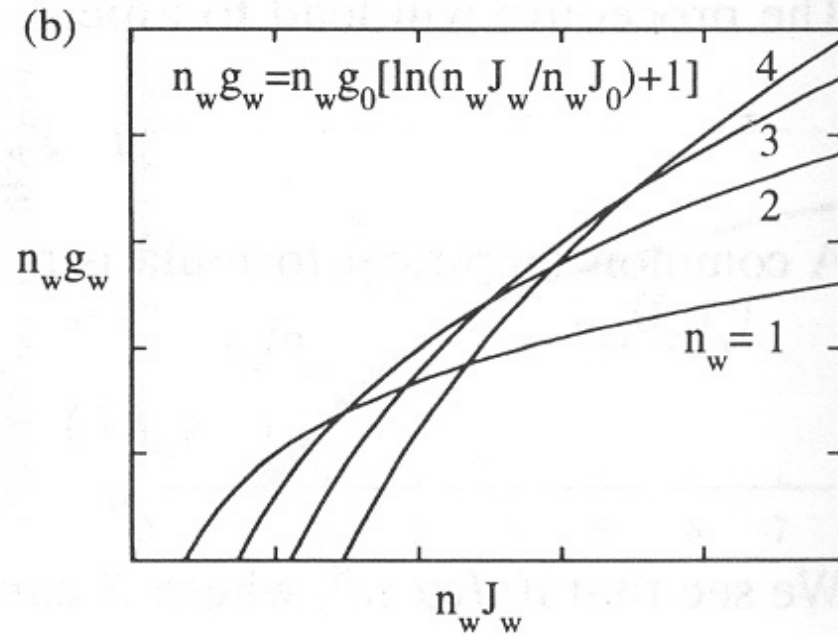
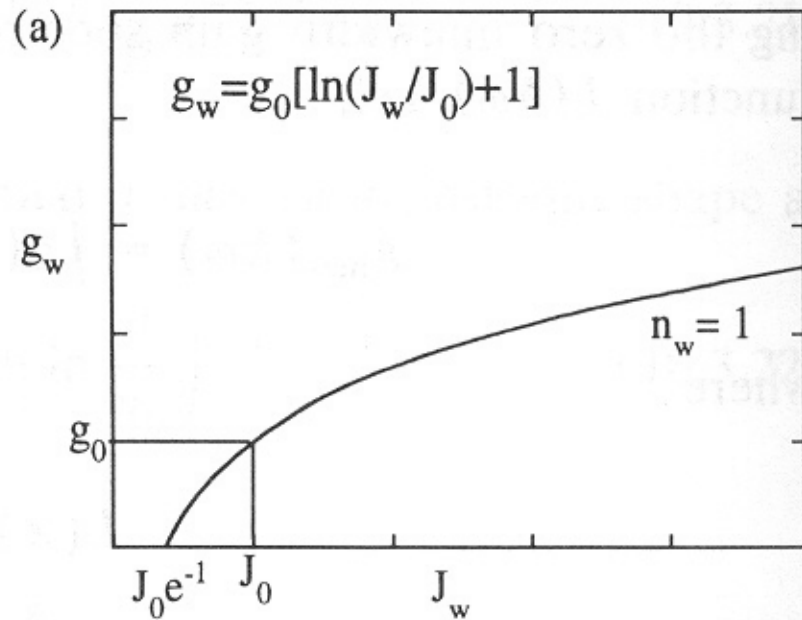


Figure 10.24. (a) Gain (g_w) vs. injection current density (J_w) relation for a single-quantum-well structure; (b) gain ($n_w g_w$) vs. injection current density ($n_w J_w$) relation for a multiple-quantum-well structure with n_w wells.

Multiple-Quantum-Well Laser

For an MQW structure with quantum wells n_w
gain($n_w g_w$) vs. the injection current density($n_w J_w$)

$$n_w g_w = n_w g_0 \left[\ln\left(\frac{n_w J_w}{n_w J_0} \right) + 1 \right]$$

(well to well coupling can be ignored for simplicity)

Obviously, the horizontal intersection is shifted to the right by a factor 2.

Related Parameters

For n_w quantum wells, the threshold current density

$$J_{th} = \frac{n_w J_w}{\eta} = \left(\frac{n_w J_0}{\eta} \right) \exp\left[\left(\frac{g_w}{g_0} \right) - 1 \right]$$

where η is the internal quantum efficiency of the injection current.

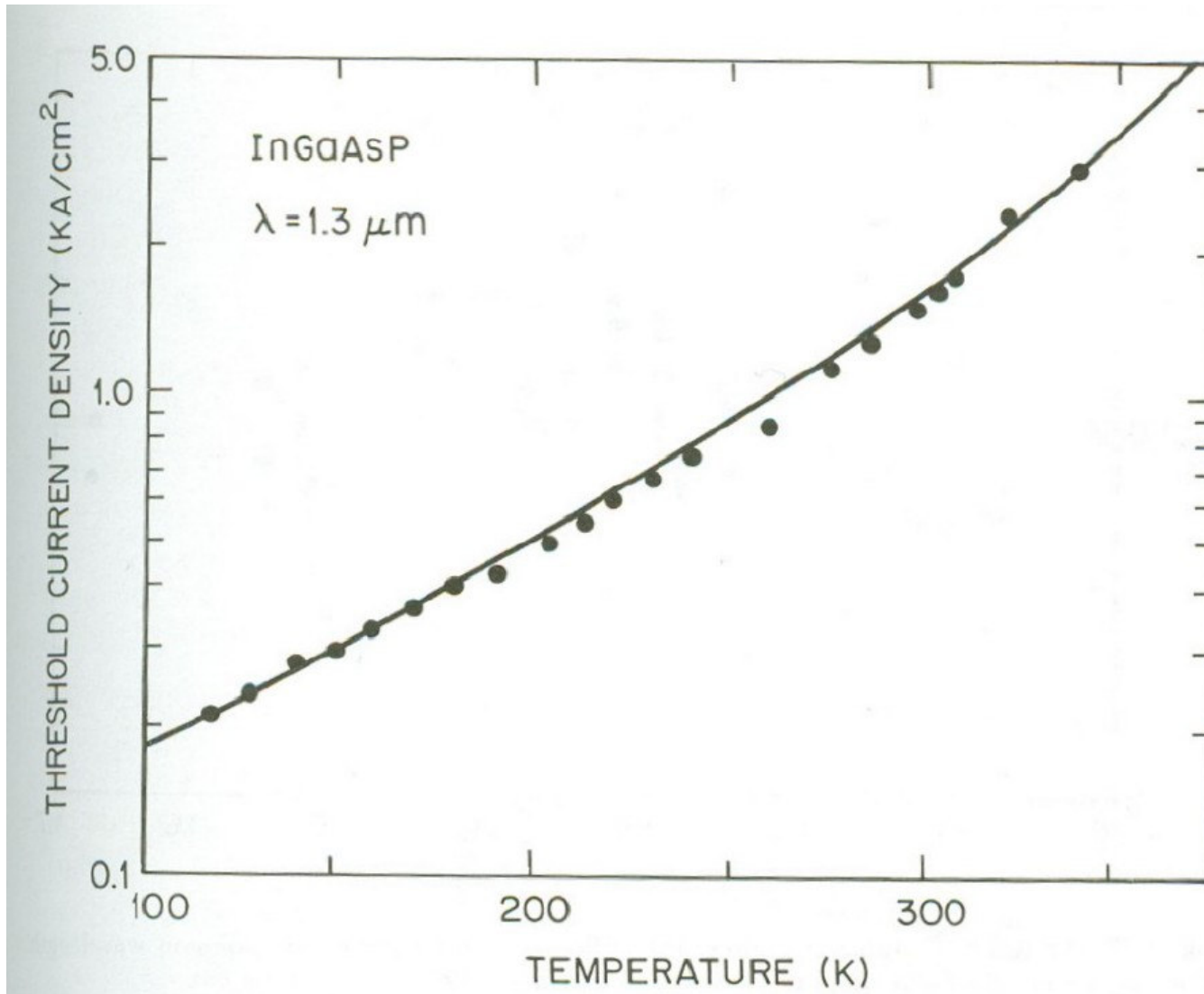
J_{th} -T Relations

The threshold current density is found to vary with temperature T as

$$J_{th} = J_0 \exp[T / T_0]$$

where J_0 is a constant and T_0 is a characteristic temperature often used to express the temperature sensitivity of threshold current density.

Temperature Dependence of Threshold Current Density



Characteristic Temperature T_0

Higher values of T_0 imply that the threshold current density and the external differential quantum efficiency of the device increase less rapidly with increasing temperatures, i.e. the laser is more thermally stable.

The high temperature sensitivity of the threshold current density of InGaAsP lasers limits their performance under high-temperature operation.

J_{th} vs the T on a logarithmic scale

From above equation, we can get the characteristic temperature T_0

$$\ln(J_{th}) = \frac{T}{T_0} + \ln(J_0)$$

$$T_0 = \frac{\Delta T}{\Delta \ln(J_{th})}$$

$\ln(J_{th})$ -T Curve

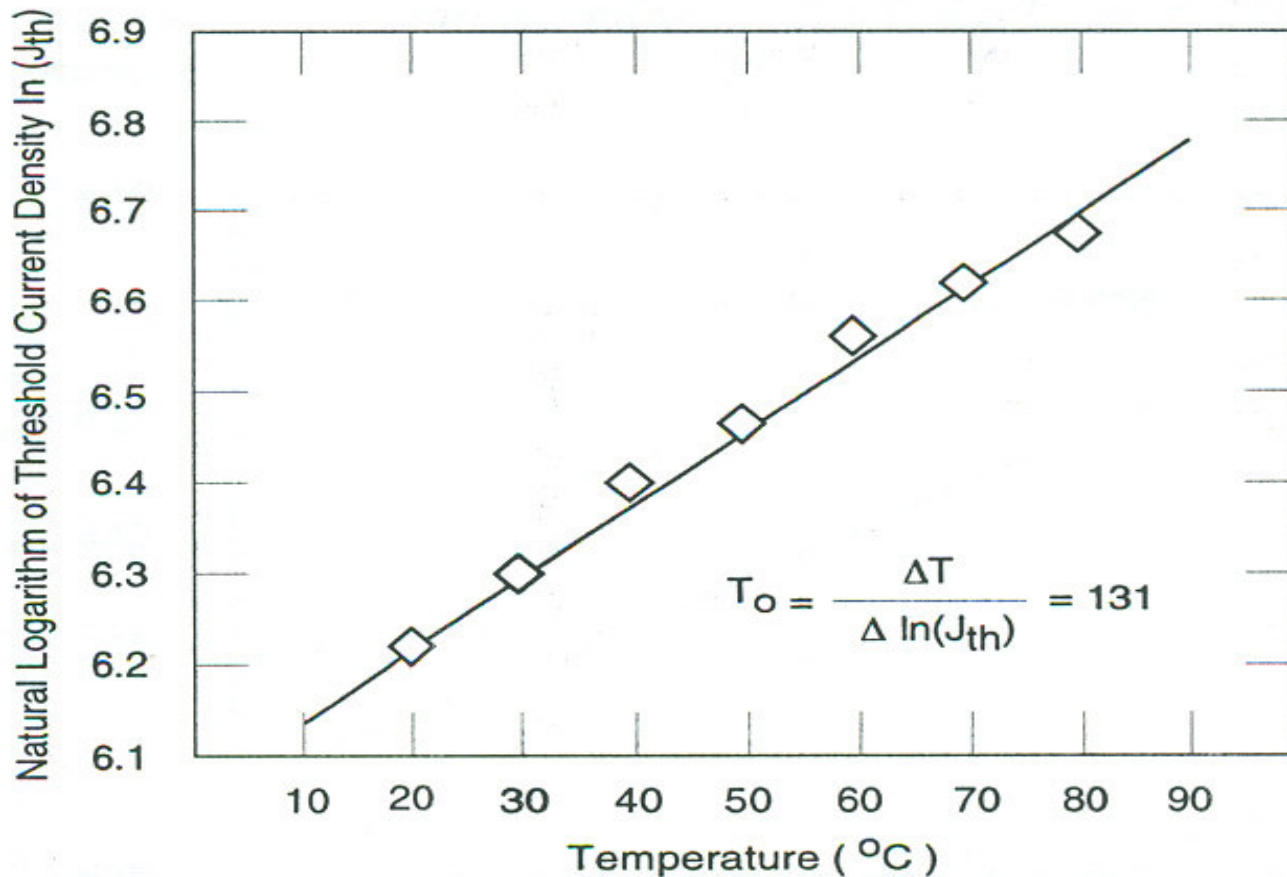


Figure 11. Graph showing the variations of the threshold current density J_{th} with increasing temperature. The inverse of the slope of the linear fit to this set of data points is the characteristic temperature T_0 value. Instead of plotting the J_{th} points one can alternatively use I_{th} data points, the outcome will be the same.