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SPREADING THERMAL RESISTANCE OF A DIODE-LASER HEAT SINK

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An approximate procedure is proposed for the determination of the effective width of a heat flux penetrating into a heat sink of a stripe-geometry diode laser. The procedure markedly reduces the computer work-time necessary for calculations of temperature profiles within diode laser crystals.

The operation of a diode laser may be disturbed by an increase in temperature within its volume, mainly due to nonradiative recombination processes; it may also be due to the reabsorption of generated radiation and Joule heating. This temperature rise leads to a deterioration in laser diode performance, causing an increase in the threshold current, a decrease in the radiation intensity, a reduction of the laser lifetime and shifts of stimulated

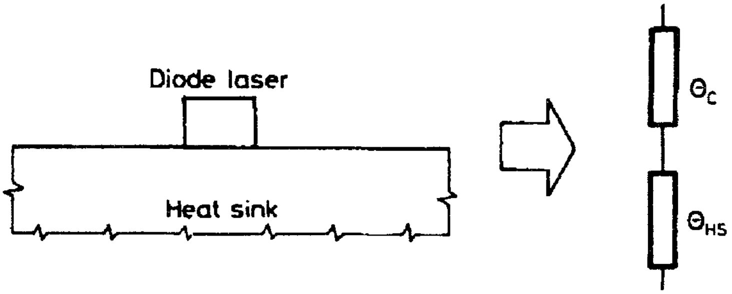

Fig.1 Component resistances of the thermal resistanse Θ_{DL} of a dioda laser: Θ_c = thermal resistance of a laser crystal, Θ_{HS} = spreading thermal resistance of a laser heat sink

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radiation modes and of the whole spontaneous radiation band on the spectral characteristics. The thermal properties of a diode laser therefore have a determining influence on its usability in various applications, e.g. in optical communication systems.

The thermal resistance of a diode laser (Fig. 1) consists of the following two parts: the thermal resistance Θ_c of a diode laser crystal and the spreading thermal resistance Θ_{HS} of a heat sink. The second factor is often neglected, although its relative participation in a total thermal resistance Θ_{DL} of a diode laser may be as high as one-quarter or even one-third [1, 2].

In the present paper, results of the analysis of the heat spreading phenomenon in the heat sink of a diode laser are presented.

The spreading thermal resistance of a heat sink

In order to determine the spreading resistance Θ_{HS} of a heat sink of stripe-geometry diode laser, the concept [3] of the effective width S_E of a heat flux penetrating into a heat sink is developed:

$$S_E = (P/Lk_\tau)\,(\partial T_A / \partial d_\tau)^{-1} \tag{1}$$

S_E is the width of a hypothetical,uniform heat flux which gives the same averaged active-area temperature T_A as the real heat spreading. This procedure provides good accuracy when applied to layers which have little lateral thermal spreading. Accordingly, it is used for a titanium bonding layer, which is rather thin ($d_\tau = 0.1 \mu m$)and has relatively low thermal conductivity ($k_\tau = 22$ W/mK) as compared with the layerss on either side. The remainder of the notation used in Eq. (1) is as follows: P is the dissipated power and L is the length of the laser resonator.

Carslaw and Jaeger [4] have shown that the mean spreading thermal resistance Θ_{HS} of a semi-infinite medium with thermal conductivity k_{HS} for a rectangular ($S_E \times L$) uniform heat source is of the following form:

$$\begin{aligned}\Theta_{HS} = (\pi k_{HS} L^2 S_E^2)^{-1}\,\{S_E^2 L \sin h^{-1}(L/S_E) + \\ + S_E L^2 \sin h^{-1}(S_E/L) + (1/3)\,[S_E^3 + L^3 - (S_E^2 + L^2)^{3/2}]\}\end{aligned} \tag{2}$$

which, for $L >> S_E$ reduces to [5]

$$\Theta_{HS} = (\pi k_{HS} L)^{-1} [0.5 + \ln (2L / S_E)] \tag{3}$$

Determination of the parameter S_E appears to be very troublesome and time-consuming: the necessary computer work-time is several times longer than that for calculations of temperature increases within a laser crystal. It therefore seems to be worthwhile to work out an approximate procedure.

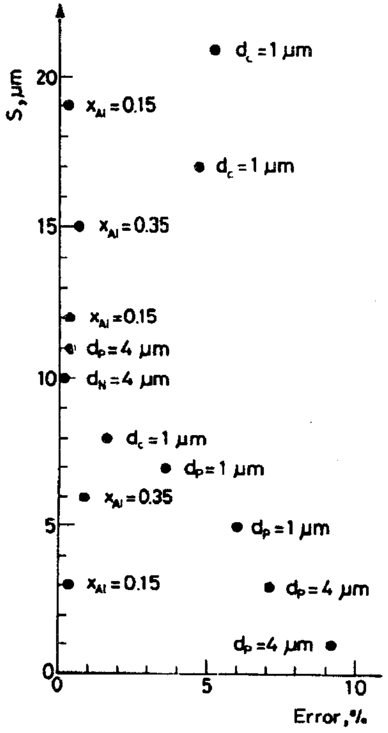

Fig. 2 Exactness of Eq. (4) in the case of simultaneous changes in stripe width S and an indicated parameter

The effective width S_E

In this section, an approximate expression for the parameters S_E is given. The expression gives S_E as a function of the construction parameters of the diode laser, i.e. the width S of its GaAs active area, the AlAs mole fraction x_{A1} of an (AlGa)As cladding-layer material, and the thicknesses d_C, d_P, d_N and d_A of the p-type capping layer, the P-type and N-type cladding-layers and active layer,respectively. The expression was derived on the basis of the results with accurate calculations performed on tens of various constructions of double-heterostructure stripe-geometry GaAs/(AlGa)As diode laser without oxide barriers. In the calculations, the method presented in refs [5,6] was used.

Table 1 Exactness of Eq. (4) if only one parameter is changed with respect to the nominal set

Parameter	Range	Error
S	1-21 μm	<0.5%
X_{A1}	0.1-0.4	<0.3%
d_C	1-4 μm	<0.5%
d_P	0.5-4 μm	<0.5%
d_N	1-4 μm	<0.3%
d_A	0.1-0.4 μm	<0.3%

The resultant approximate expression reads as follows:

$$S_E = S_{E,o}(S) \,.\, \Omega_c(d_c) \,.\, \Omega_P(d_P) \,.\, \Omega_A(d_A) \,.\, \Omega_N(d_N) \,.\, \Omega_x(X_{A}1) \qquad (4)$$

with

$$S_{E,o}(S) = 31.9 + 0.339 \,.\, S^{1.35} \qquad (5)$$

$$\Omega_c(d_c) = 0.732 + 0.139 \,.\, (d_c)^{0.976} \qquad (6)$$

$$\Omega_P(d_P) = 0.5560 + 0.2234 \,.\, d_P \qquad (7)$$

$$\Omega_N(d_N) = 1.841 - 0.753 \,.\, (d_N)^{0.160} \qquad (8)$$

$$\Omega_A(d_A) = 0.9737 + 0.1317 \,.\, d_A \qquad (9)$$

$$\Omega_x(X_{A1}) = 0.5737 + 0.4992 \,.\, (X_{A1})^{0.1176} \qquad (10)$$

All the dimensions should be applied in microns.

The accuracy of the above expression is not worse than 0.5% if only one parameter is changed (cf.Table 1) with respect to the nominal set of parameters listed in Table 2. This accuracy is considerable worse in the event of changes in two parameters (cf.Table 3 and Fig.2).

Table 2 Nominal set of parameters

Parameter	Notation	Value	Unit
Stripe width	S	10	μm
AlAs mole fraction of a cladding layer material	X_{Al}	0.25	-
Thickness of the layers:			
p-type capping	d_C	2	μm
P-type cladding	d_P	2	μm
N-type cladding	d_N	2	μm
active	d_A	0.20	μm

Table 3 Maximal errors in the event of changes in two parameters with respect to the nominal set

First parameter		Second parameter		Maximal error
Notation	Range	Notation	Range	%
d_C	1-4 μm	d_P	1-4 μm	6.7
d_C	1-4 μm	d_N	1-4 μm	1.2
d_C	1-4 μm	X_{Al}	0.15-0.35	0.8
d_P	1-4 μm	d_N	1-4 μm	1.8
d_P	1-4 μm	X_{Al}	0.15-0.35	2.4
d_N	1-4 μm	X_{Al}	0.15-0.35	2.8

Conclusion

An approximate procedure for determination of the effective width S_E of a heat flux penetrating into a heat sink of a diode laser has been proposed in the present paper. The procedure considerably accelerates computer calculations of temperature profiles within diode laser.

* * *

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Zusammenfassung - Es wird ein Näherungsverfahren zur Bestimmung der effektiven Stärke eines Wärmestromes gegeben, der in die Kühlkörper eines streifenförmigen Diodenlasers eindringt.Das Verfahren senkt erheblich die zur Berechnung der innerhalb der Diodenlaserkristalle auftretenden Temperaturprofile notwendige Rechnerzeit.