OPTIMAL THERMOELECTRIC COOLING IN LASER DIODE SUB-ASSEMBLIES

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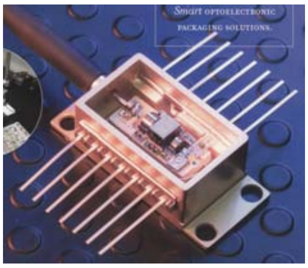
Introduction

Thermoelectric (TE) cooling is widely used in optoelectronics and telecommunication for cooling and temperature stabilization of laser diodes (LD), superluminescent diodes (SLD), Diode Pumped Solid State lasers (DPSS), etc. A TE module/TE cooler/TEC has become inherent in most such applications. In the international standards Telcordia GR-468 [1] requirements to the TE module are given as to a standard component of laser devices.

TE modules solve the major problems of LD effective operation. Cooling is important for maintaining laser lifetime, preventing its premature failure [2,3], advantageous values of laser emission parameters [4]. The thermal stabilization of operating conditions is necessary for laser output parameters stability.

If in other areas (photodetectors, etc.) alternative ways of cooling compete with the TE method, in laser engineering there are no alternatives to TE cooling due to modules diminutiveness (~ 1 mm), high cooling capacity density (~10-30 W/cm^2), high accuracy of temperature stabilization (0.01 - 0.001 ^{o}C), and reliability. TE module average operating time (MTBF) is more than 300 000 hours; failure rate is units per million device×hours. It is important to emphasize the TEC ecological safety. TE modules are maintenance-free, contain no harmful coolants. State-of-the-art TECs meet the RoHS Directive [5].

Nowadays semiconductor lasers are manufactured in volume. As a consequence, quite standard designs [6,7,8] have been settled in this area. At the telecommunication market the lasers (send-receive modules, amplifiers) are most commonly produced in the “Butterfly” package or a smaller “TOSA/ROSA” housing. Powerful pumping lasers involve the packages TO3 or HHL. Tiny semiconductor lasers VCSEL mounted on the packages TO46/TO39 are applied as transmitters in optical fiber systems.



Requirements to TECs for these applications are also standard. However it is possible to show that by careful TEC *optimization* and admissible deviation from the standard values it is possible to increase TE cooling efficiency, that is *to provide a required level of cooling at the TEC minimal electric power*. It is a relevant problem as the TEC consumption is commonly a considerable part of the whole system power. For newer laser designs (TOSA, VCSEL) it is possible to apply the optimal solution initially.

General reasoning and optimization aspects in the TO-style designs for laser applications and others were studied and reviewed in papers [9,10].

This paper actually gives the outlines of quite a more wide-ranging and detailed work [11]. In this work typical cooling problems in laser engineering are analyzed, estimations of an optimality of “standard” TE coolers used now in these applications are offered. Optimum solutions are searched. And, in spite of the lack of opportunities to change standard designs, possible ways of optimization of cooling efficiency for these applications are investigated.

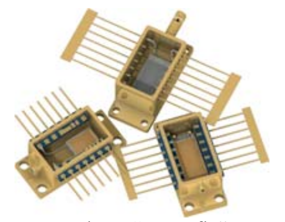
Examples of Optimizing of Laser Diodes TE Cooling

The work we are presenting offers an optimizing study of most widespread standard LD cooled systems: “Butterfly”, TO3, HHL, TOSA, and VCSEL. Here, being space-limited, we only give a mosaic of the most demonstrative instances of all the stages of the work.

Following the typical LD requirements [4, 6-8, 13-19], we suggest two temperature levels of the cooled object: T_{cold}=20ºC and 35 ºC. The package base temperature, unless otherwise specified, is T_{hot}=75 ºC. The typical environment is air. The designations are: L is the TEC pellet height, P denotes the TEC power consumption, U and I are its voltage and electric current, T_{hotTEC} stands for the TE module hot side temperature. Single-stage TECs are considered.

The analysis in each of the sections (“Butterfly”, TO3, HHL, TOSA, VCSEL) has the following logic.

1) <u>Analysis of manufacturers’ typical requirements</u>. E.g. for the sub-assemblies “Butterfly” the information on the manufacturers of Telecom lasers [4,6,7] is analyzed. There are found three groups of applications:

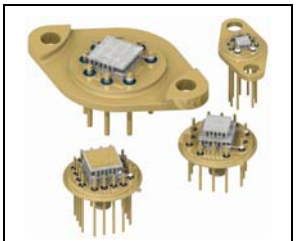


Package “Butterfly”

1) transmitting laser modules,
2) superluminescent diodes (SLD), and
3) pumping lasers.

As for the heat load values, two niches of applications can be determined: low power (groups 1 and 2: below 150 mW) and high power (group 3: up to 1.5 W).

2) <u>Search for the optimal TE module.</u> For the estimated value of a full heat load under the given boundary temperature conditions a TE module with an optimum relation of geometrical factor



TO3-package

(L/S) and the number of thermoelements in the module is found. If necessary, the close to the typical variant is taken preferable.

For the TO3 system (a powerful niche) the solution for the optimum pellet height L at a given section S and thermoelements number is illustrated in Fig. 1. The optimal value is marked: L=0.5 mm.

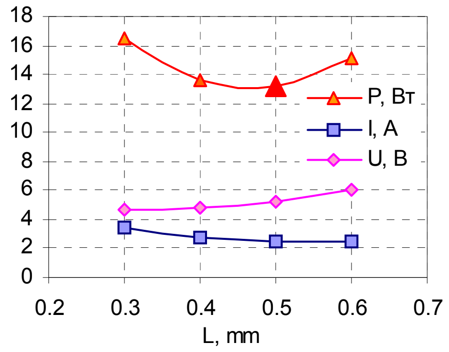
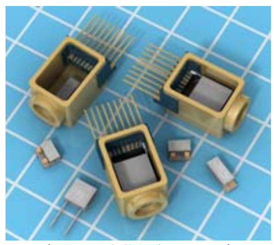


Fig. 1. TEC 1MC06-046-xx [12] optimal pellet height in the package TO3 (Cold-rolled steel - CRS): cooling 75-20 ºC; heat load 3.1 W [13,14]; air.

<u>2. TE Module Optimization.</u> In the conditions considered, for the found TE module the optimal choice of ceramic substrates is analyzed. The results are characteristic of both high- and low-power systems.



Package TOSA (Transmitter Optical SubAssembly)

Here we give the exemplary data of the package TOSA (low-power alternative for “Butterfly”) – Fig. 2.

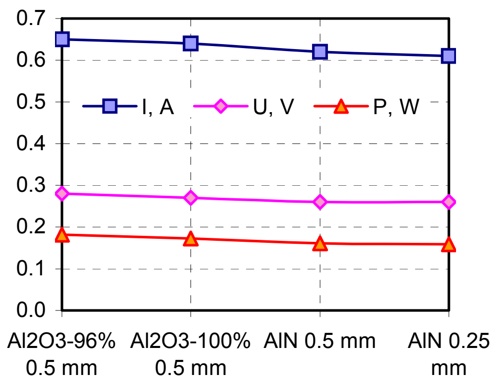
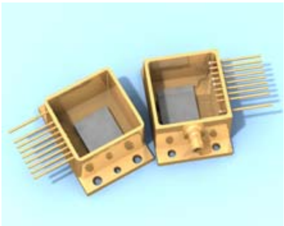


Fig. 2. Operational parameters of the TE module 1MD04-004-05 [12] in the package TOSA (kovar) via ceramics: cooling 75-35 ºC; heat load 0.1 W [15]; air.

When choosing ceramics of smaller thermal resistance the TEC power consumption can reduce 12-20 %.

4) Package Optimization. For the chosen TE module the optimal material of the housing base as well as optimal gas filling of the housing is studied. Let's solve this problem for the system HHL.



Package HHL (High Heat Load)

Table 1. Operational parameters of the TE module 1MC06-142-05 [12] in the package HHL via the package material: cooling 75-20 ºC and 75-35 ºC; heat load 10 W [13,14,16,17,18]; air.

	Package base material	Kovar	CRS	CuMo (20-80%)	CuW (20-80%)
	Rt, K/W	0.68	0.23	0.07	0.06
75-20ºC	**I, A**	N/a*	n/a	2.53	2.48
	U, V	n/a	n/a	16.1	15.8
	P, W	n/a	n/a	40.8	39.2
	T_{hotTEC}, ºC	n/a	n/a	78.6	77.9
75-35ºC	**I, A**	n/a	1.79	1.62	1.61
	U, V	n/a	11.8	10.6	10.5
	P, W	n/a	21.0	17.1	16.9
	T_{hotTEC}, ºC	n/a	82.4	77.0	76.6

*n/a – the mode is not achievable

Note that for the kovar package neither cooling mode is possible. For the cold-rolled steel (CRS) package the operating conditions 75-20 ºC cannot be achieved.

The selection of a higher thermal conductivity material of the housing base can save up to 25 % of power consumption.

Let's simulate the operational parameters of the optimum TE module in the package HHL, varying gas filling - Fig. 3.

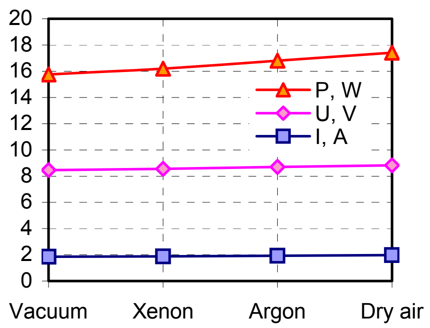


Fig. 3. Operational parameters of the TEC 1MC06-096-05 [12] in the package HHL (CuW) via environment: cooling 75-20 ºC; heat load 5 W [13,14,16,17,18].

In comparison with the air filling, in the ideal case of vacuum the power consumption is 10 % lower, in argon it is 6 % smaller, in xenon the decrease is 3 %.

5) The analysis of operational conditions. For the chosen system of the optimum TE module the performance data in different conditions (ambient temperature, heat sink) are studied.

Package VCSEL (Vertical Cavity Surface Emitting Laser)

LDs can be applied in a wide range of the ambient temperature 40-85 ºC (75ºC is taken typical). Let's consider this range of the ambient temperature T_{amb} for the problem VCSEL, in the housing TO46. We suppose that the value T_{amb} coincides with the package hot side temperature T_{hot}.

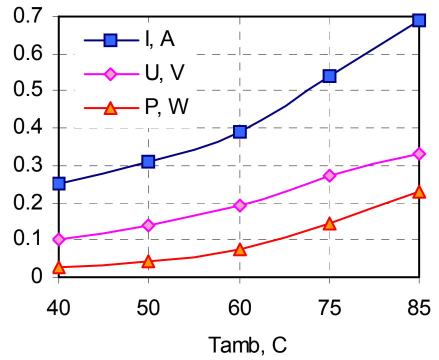


Fig. 4 Operational parameters of 1MD04-003-08 [12] in the package TO46 via the ambient temperature: cooling down to 20 ºC; heat load 0.05 W [19];air.

We see that overheating of the system can involve TEC significant (>50%) overpower.

Let us consider the heat dissipation from the system. Naturally, the efficient heat rejection from the hot side of the housing is especially important for powerful applications. Here we give the heat sink thermal resistance optimal values required for pumping lasers TEC “Butterfly” systems – see Fig. 5.

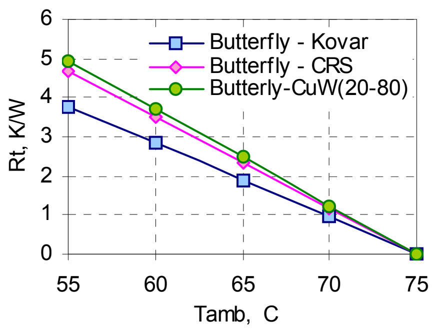


Fig. 5 The heat sink thermal resistance required for the system "Butterfly" with the optimum TEC 1ML06-029-05AN [12] for various materials of the package base: cooling to 35 ºC; the package base temperature T_{hot} is 75 ºC; heat load is 1.5 W; air.

The result is quite reasonable: the higher the ambient temperature at the fixed T_{hot}, the harder the heat rejection, the smaller thermal resistance of the heat sink should be. For the lower-power applications the heat sink requirements are less stringent.

Conclusion

Here we present and in work [11] we give in detail an optimization study of the LD TE cooling. Several levels of optimization are considered: that of the TE cooler itself (design and materials), optimization of a package (materials and gas filling), and the dependence of the efficiency on the operational conditions (ambient temperature and heat sink thermal resistance).

The study covers all the state-of-the-art LD applications, from low-power to high-power systems, both for standard and newly-born laser designs, in a wide variety of possible packaging solutions.

The offered analysis gives quantitative estimations of efficiency of optimization, allows minimizing up to 40-50 % power consumption of the system and finding an optimum both for efficiency of cooling and LD long-life reliability.

The work can be of interest both in TE cooling and telecommunication engineering.

Literature

1. Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment. Telcordia Technologies Generic Requirements GR-468-CORE Issue 2, September 2004, pp. 7-1 – 7-4
2. Reliabilities Assurance Practices for Optoelectronic Devices in Loop Applications. Bellcore. Technical Advisory TA-NWT-000983 Issue 2, December 1993, pp. 5-15 – 5-18
3. L.A Johnson. Laser Diode Burn-un and Reliability Testing. IEEE Communication Magazine. Feb. 2006, www.ilxlightwave.com/whitepapers/laser-diode-reliability-burn-in-testing.pdf
4. www.superlumdiodes.com
5. www.rohs.gov.uk/Docs/ PressStatementJuly1st06.doc
6. www.bookham.com
7. www.em4inc.com
8. www.jdsu.com
9. V.A. Semenyuk. Advances in Development of Thermoelectric Modules for Cooling Electro-Optic Components. Proc. XXII Int. Conf. on Thermoelectrics, France, 2003. P. 631-636
10. V.A. Semenyuk. Thermoelectric Cooling of Electro-Optic Components. Thermoelectric Handbook. Macro to Nano (edited by D.M. Rowe). CRC Press, 2006. P. 58-1 – 58-20.
11. L.B. Ershova, G.G. Gromov, L.B. Optimal Thermoelectric Cooling in Laser Applications. FIAN, 2008 (in press)
12. www.rmtltd.ru
13. www.qphotonics.com
14. www.bjlaser.com/index/hpd/packages
15. www.sourcephotonics.com
16. www.laserdiode.com
17. www.sony.net/Products/SC-HP/cx_news/ vol20/pdf
18. www.innolume.com
19. www.finisar.com