New Miniature Thermoelectric Coolers of the Company RMT

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Abstract

Recently the demand for telecommunication equipment for high-rate data traffic has significantly increased. At the same time 10G, 40G, and 100G transceivers and transponders welcome more and more miniature electronic components. The company RMT Ltd. introduces a new line of miniature thermoelectric (TE) single-stage modules developed specially as low-current solutions for cooled miniature telecommunication applications. TE modules of the new 1MD015 Series have planar dimensions less than 1,5 mm^2 and height 0,55 mm and lower. The new products meet high performance requirements of transceiver components with low power consumption. The paper describes fundamentals of bulk elements technology and properties of TE materials used in the production. The limits of miniaturization of TE modules manufactured with this technology are analyzed. The calculated and experimental characteristics of the new modules are given. The parameters of the developed TE modules and thin-film analogues are compared. The range of possible operational modes in telecommunication applications is simulated.

Keywords

Miniature Thermoelectric Module, Bulk, Telecommunication

Introduction

Miniaturization has determined the direction of development of electronic active components for a long time, as this reduces the power consumption and increases the mounting density. With thermoelectric products, the situation is somewhat different.

In case the contact and commutation resistances are neglected, the power consumed and cooling capacity are proportional to the geometric factor s/l, where s is TE module elements cross-section, and l is their height, i.e. a decrease in the elements height should not result in TE module efficiency reduction. Therefore, in order to reduce losses due to the Joule heat at the commutation, a decrease in the height of elements must be accompanied by a reduction in their cross-section. It would seem that the most evident solution of this problem is in thin-film elements, but in this technology it is very difficult to keep a good value of Figure-of-Merit $Z = \alpha^2\sigma/\kappa$, as the thin-film TE modules data show [1] (α is the Seebeck coefficient, σ is electrical conductivity, κ is thermal conductivity of the elements material). To obtain low-high elements with a small cross-section from bulk thermoelectric materials, it is necessary to take measures to strengthen them, since the strength of the original single-crystal materials is extremely small due to the layered structure in which groups of five atomic layers are connected with each other by weak Van der Waals bonds.

Principle Ideas of TE Module Miniaturization

The mechanism of TE materials strengthening has long been known and consists in the creation of a finely dispersed structure that does not allow a growth of microcracks arising under mechanical stress. The simplest way to create a finely dispersed structure is to grind the original material to the desired dimensions and then to expose it to the hot pressing. However, it does not lead to the elimination of pores that can become a source of mechanical stresses themselves. To eliminate the pores, it is necessary to compress the material under pressure gradient conditions (forging, extrusion), which will result in the displacement of the pores into the region of lower pressures.

In the company RMT the strengthening of the material was carried out by hot extrusion. The compressive force of the extruded material was not less than 190 MPa, which made it possible to obtain pellets of such small dimensions.

The TE modules pellets were cut by the high-precision disc cutting machines.

The initial thermoelectric single-crystal material has a strong anisotropy of electrical and thermal properties. For p-type materials, the anisotropy of the electrical and thermal properties is approximately the same [2], so in them there is no anisotropy in thermoelectric efficiency Z, and the thermoelectric properties of the extruded material do not depend on the texture in it.

In the n-type materials, the anisotropy of the electrical and thermal properties differs almost 2 times [3,4], which leads to a noticeable anisotropy of the thermoelectric efficiency. The thermoelectric efficiency in the direction of the cleavage planes turns out to be 2 times higher than in the perpendicular direction, hence the extrusion process should provide a well-defined texture with a predominant direction along the extrusion axis.

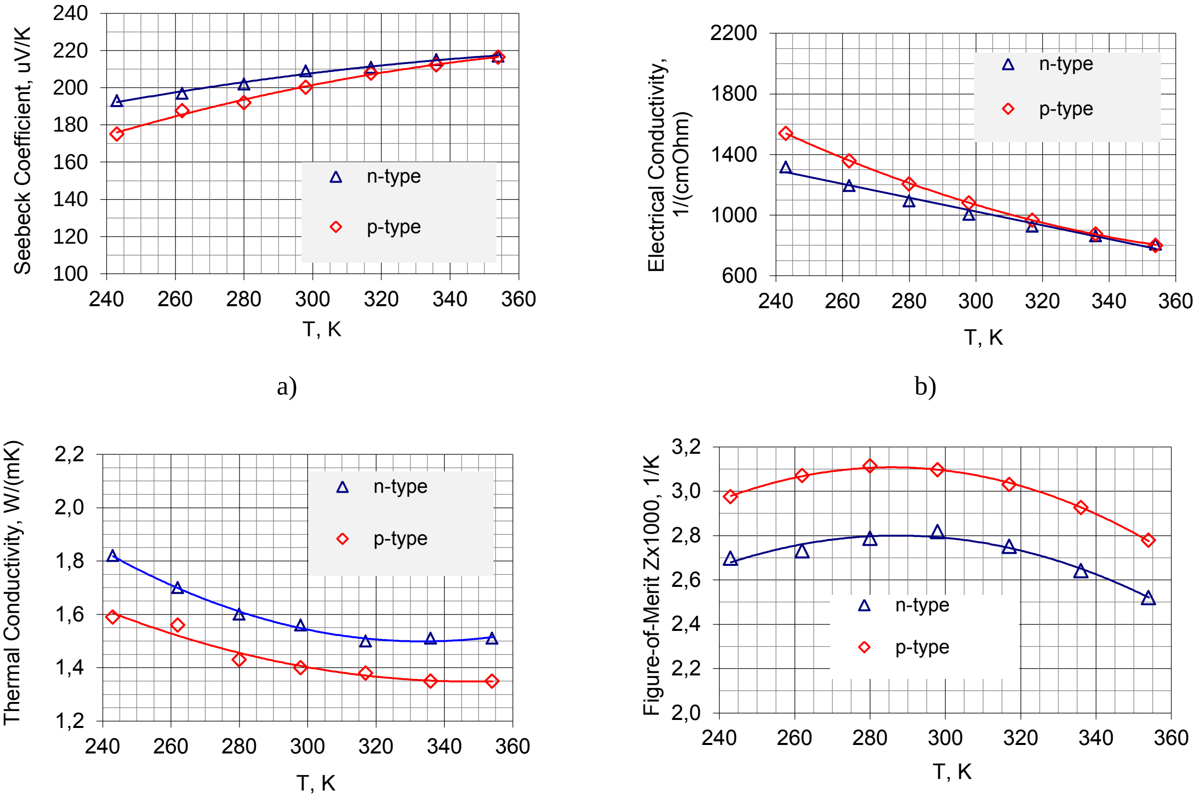
To obtain efficient TE modules from extruded materials, in addition to good mechanical properties, good thermoelectric properties are needed.

Typical values of thermoelectric properties of RMT extruded materials at 300 K are given in Table 1.

Table 1 – Typical TE Material parameters properties at 300 K

Type	**α, μV/K**	**σ, $Ohm^{-1}xcm^{-1}$**	**κ, W/(mxK)**	**$Zx10^3$, K^{-1}**	**ZT**
n	205	1050	1,5	2,9	0,87
p	213	990	1,5	3,1	0,93

Fig. 1 gives typical temperature dependences of TE material parameters.



a) b)

c) d)

Figure 1 - Temperature dependences of TE material parameters a)Seebeck coefficient, b) electrical conductivity, c) thermal conductivity, d) Figure-of-merit.

The efficiency of the module depends on the value Z of the TE materials and on the thermal losses in the TE module design. Contact losses are especially important for micromodules.

The contact resistances [5,6,7], measured from the ΔT_{max} dependence on the height of the module elements, are approximately 2×10^{-6} Ohm×cm^2. Such values of contact resistances enable 0,2-0,3 mm high pellets without significant efficiency degradation.

In Fig. 2 the calculated dependence of ΔT_{max} of TE module on the height of the pellet for the contact resistance 2×10^{-6} Ohm×cm^2 is given.

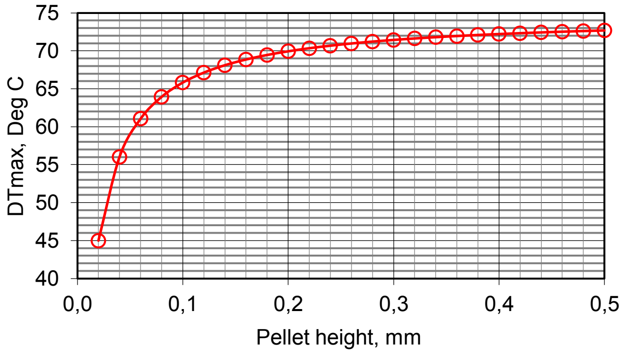


Figure 2 – Dependence of TEC ΔT_{max} on pellet height, estimated for contact resistance $2x10^{-6}$ Ohmcm^2.

We see that for the pellet height less than 0,1 mm, the TE module efficiency is abruptly decreasing.

Keeping in mind the above-said, a series of single-stage micromodules 1MD015 with pellets 0,2-0,25-0,3 mm in height and 0,15x0,15 mm^2 cross section was developed.

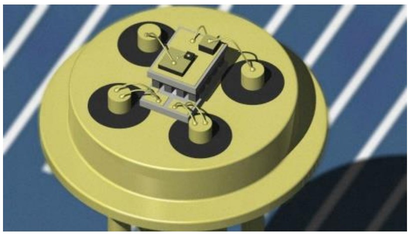


Figure 3 - TE module 1MD015-010-03 mounted on TO-46 header

An example of TE modules of the series 1MD015 developed is given in Fig. 3. The modules of this series are based on the technology of high density pellets assembling. The modules have a unique combination of a miniature cross-section of pellets and a distance of 100 μm between them. This allows the density of 1100-1200 elements per 1 cm^2. By default, AlN ceramics 0,1 mm thick is used.

Table 2 gives the specification of the developed modules for 300 K in vacuum.

Table 2 – specification of TE modules developed at 300 K in vacuum

TE module	ΔT_{max}, K	Q_{max}, W	I_{max}, A	U_{max}, V	R, Ohm	AxB, mm^2	CxD, mm^2	H, mm
1MD015-003-xxx								
1MD015-003-020	70	0,13	0,61	0,4	0,53	0,5x0,8	0,5x1,0	0,45
1MD015-003-025	71	0,10	0,48		0,67			0,5
1MD015-003-030	72	0,08	0,40		0,80			0,55
1MD015-004-xxx								
1MD015-004-020	70	0,16	0,61	0,5	0,71	1,0x0,5	1,0x0,8	0,45
1MD015-004-025	71	0,13	0,48		0,89			0,5
1MD015-004-030	72	0,11	0,40		1,06			0,55
1MD015-006-xxx								
1MD015-006-020	70	0,25	0,61	0,75	1,07	1,0x0,8	1,0x1,1	0,45
1MD015-006-025	71	0,20	0,48		1,33			0,5
1MD015-006-030	72	0,17	0,40		1,59			0,55
1MD015-008-xxx								
1MD015-008-020	70	0,33	0,61	1,0	1,43	1,0x1,0	1,0x1,3	0,45
1MD015-008-025	71	0,27	0,48		1,78			0,5
1MD015-008-030	72	0,22	0,40		2,13			0,55
1MD015-010-xxx								
1MD015-010-020	70	0,41	0,61	1,25	1,78	1,0x1,3	1,0x1,6	0,45
1MD015-010-025	71	0,33	0,48		2,22			0,5
1MD015-010-030	72	0,28	0,40		2,66			0,55

Here AxB is the surface of the cold side of the module, CxD is the surface of the module's hot side, and H is the height of the module.

In the company RMT a system for designing and simulation of TE modules has been developed, including low height ones. This system gives good agreement of the calculated values with the experiment. Table 3 compares the theoretical calculation and the results of direct measurements using the TE module example 1MD015-010-025.

Table 3 – measurements and calculations of TE module standard specifications at 300 K, vacuum

Parameter	**Direct measurement**	**Calculations**
ΔT_{max}, K	72	71
I_{max}, A	0,502	0,48
Q_{max}, W	-	0,33
U_{max}, V	1,298	1,25
R_{AC}, Ohm	2,21	2,22

We see that the experimental and theoretical data are in good agreement. The value of Q_{max} was not measured because of technical difficulties due to the small size of the module.

Let us compare the parameters of the developed modules with similar modules produced by the thin-film technology using the example of Micropelt modules [8]. The closest analog for the size of the cooled side is given in Table 4. The data are given in the conditions of the hot side temperature at 85 °C in the air, as given by the manufacturer of the thin-film modules.

Table 4 – Comparison of parameters of thin-film TE module MCP-D403 (Micropelt [8]) and developed module 1MD015-010-20 (RMT Ltd.) at 85 °C in the air

TE Module	ΔT_{max}, °C	Q_{max}, W	I_{max}, A	U_{max}, V	R, Ohm	AxB, mm	H, mm
MCP-D403	54	0,67	0,24	5,5	23	1x1,5	1,09
1MD015-010-020	85	0,50	0,56	1,6	2,32	1x1.3	0,45

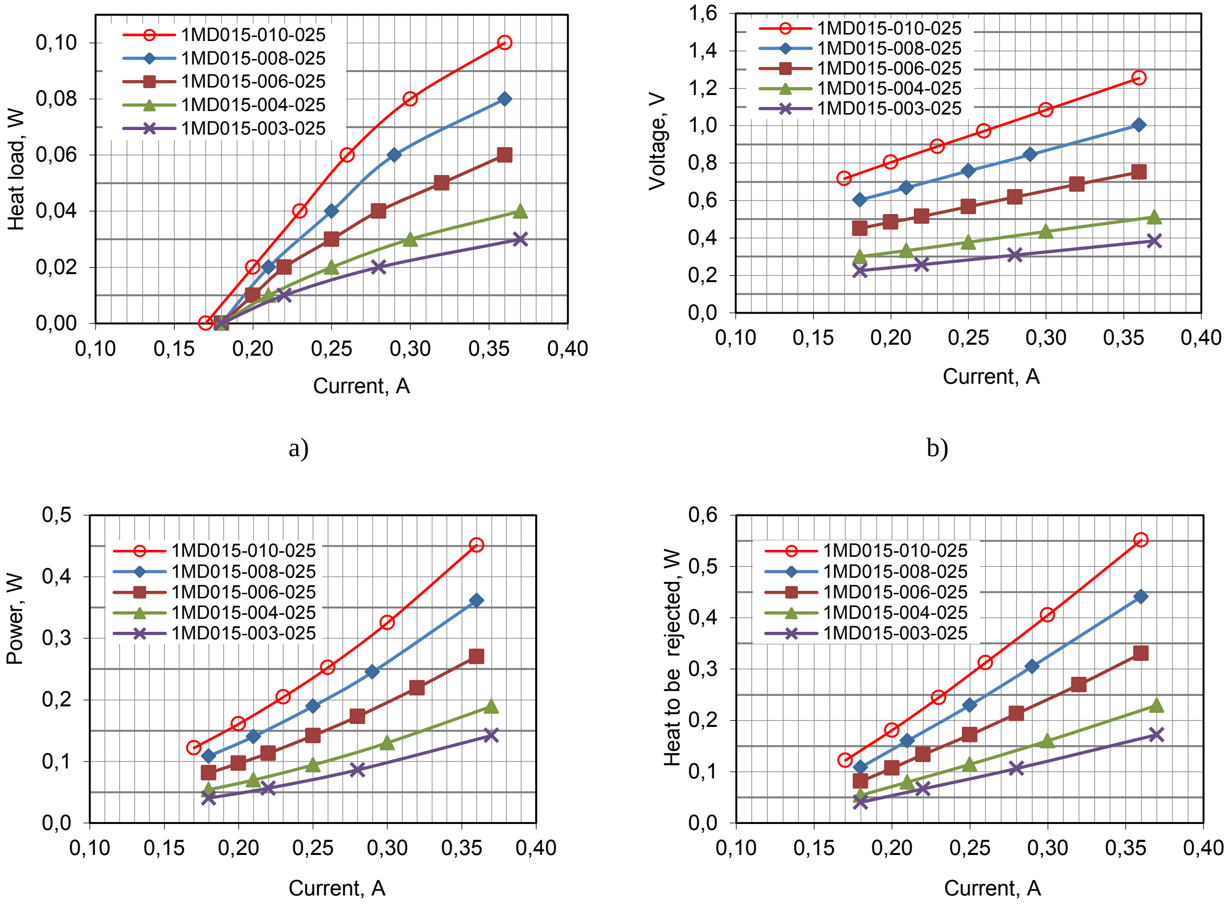
We would like to note that the overall dimensions of the modules of the 1MD015 series, the height in particular, are even smaller than the overall dimensions of the thin-film modules, which is important for miniature headers.

On the one hand, we see that for the thin-film TE module, the value of the cooling capacity Q_{max} is about 25% higher. It can be explained by a different geometric factor and a larger number of elements in the thin-film module. However, if necessary, it is possible to increase the cooling capacity for a bulk micro-module by a bigger number of elements.

On the other hand, the bulk module has ΔT_{max} more than 30 ºC higher. This is an essential argument for 3D miniaturization technology in telecommunication applications, because it is usually necessary for TE modules used in this area to cool from 75-85 ºC to room temperature 20-25 ºC. We see that the thin film module provides cooling from 85 ºC to the temperature of 31 ºC minimum under the condition of zero heat load. It can be estimated that from 75 ºC the minimum temperature of the cooled object is about 25 ºC. With a non-zero heat load, the cooled electronic component will be overheated above the required temperature value.

Such a small value of ΔTmax of the thin-film module can be explained by the effect of the contact resistance. A possible reason is also in the fact that poorly textured polycrystalline films of the n-type thermoelectric material have a lower value of the figure-of-merit Z [7].

Let us consider the operational parameters of the developed TE modules under typical conditions of telecommunication applications [9]: the temperature of the cold side is 20ºC, the hot side of the module is at 75ºC, the environment is air. In Fig. 4 the performance plots are given to illustrate the module 1MD015-0xx-025 in operation.



a)

b)

c)

d)

Figure 4 – Performance plots for the TE modules 1MD015-0xx-025 when cooling from 75 ºC to 20ºC in the air: a) heat load vs electric current, b) voltage-current characteristics, c) power consumption vs electric current, d) heat to rejected from the TE module hot side vs electric current.

The optimal heat load for the modules in the above-described application conditions is within the range up to 100 mW, consumption up to 500 mW, voltage up to 1,3 V, the current range up to 0,4 A.

Conclusions

Unique miniature TE modules with low current and low energy consumption have been developed within the bulk technology. The TE modules of the MD015 series are optimal for telecommunication transceivers with active temperature stabilization (for example, TO-can TOSA), VCSEL and miniature LD-applications in small form factors (TO46 and TO56 and smaller).

The given analysis shows that the further reduction of the height of elements for the bulk technology is limited by the value of the contact resistance and does not result in the TE module efficiency maintenance. It might be accompanied by some increase in the cooling capacity, though.

The comparison of the parameters of the developed bulk modules with thin-film analogs showed that the modules of both technologies have their advantages. However, in the typical temperature conditions for telecommunication applications, the use of thin-film modules is difficult. At the same time, new TE modules MD015, created by the bulk technology, as shown by the simulation of their work, are very promising.

Thus, the data in the work show that the low height TE modules using the bulk technologies can successfully compete with thin-film thermoelectric modules both in size and thermoelectric characteristics.

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