STUDIES ON THE OPTIMIZATION OF MATERIAL PARAMETERS OF SOME THERMOELECTRIC SIGNAL AMPLIFIERS

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Abstract

In this study, the optimization of the parameters of the materials in the thermoelement and control circuits of the thermoelectric signal converters(TSC) has been done by using barium titanate, Ti_2O_3, and VO_2 based alloys. Important values of the order of $10^3 - 10^4$ for the voltage amplification coefficient of the TSA were obtained.

Key words:thermoelectric signal converters (TSC), thermoelectric signal amplifiers (TSA), optimization of material parameters, voltage amplification coefficient

1 Introduction

In the last two decades a lot of theoretical and experimental research have been done on thermoelectric energy converters (TEC) and many new and interesting apparatus and devices have been developed. Important problems needed to solve were: i) finding out and improving the physical properties of the thermoelectric apparatus and devices, ii)production of new materials which have high efficiencies, wide working temperature intervals and are ready for application, iii) increasing the useful work coefficient of the thermoelectic converters. The solutions of these problems will lead to

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the production of new systems and multi functional devices.

By using the Peltier effect ,creating a small temperature gradient at the junction area of the thermoelement , the cooling (or heating) coefficient has been increased noticibly, [1]-[3]. Thus the opportunity of effective control of the electrical, magnetic and optical parameters of the materials, whose such properties vary strongly in the narrow temperature range with the consuption of very small energy, became possible. All these developments provide the opportunities for making new thermoelectric signal converters (TSC). In this work, studies on the optimization of material parameters of some alloys of barium titanate base, Ti_2O_3 , and VO_2 materials which are used in TSA, have been done.

2 Methods

When metal-semiconductor phase transition materials are used in the control unit of TSC, the voltage amplification coefficient β is defined as follows [1]

$$\beta = \left[\frac{1}{\alpha}\frac{\mathrm{ZT}}{(1+\mathrm{ZT})}\right]\left[\frac{\mathrm{Er}}{(\mathrm{R}+\mathrm{r})^2}\frac{\mathrm{dR}}{\mathrm{dT}}\right] = \delta_1\delta_2 \quad (1)$$

However, if ferrolectric phase transition materials are used in the control unit, Eq.(1) changes into

$$\beta = \left[\frac{1}{2\alpha}\frac{\mathrm{ZT}}{(1+\mathrm{ZT})}\right]\mathrm{E}\frac{\mathrm{d(LnC)}}{\mathrm{dT}} \quad (2)$$

where Z is the effective yield coefficient of thermoelement branch materials in the thermo energy converters (TEC) and defined as follows,

$$\mathrm{Z} = \frac{\alpha^2\sigma}{\mathrm{H_c}}$$

Here α, σ and H_c are the thermo electromotor force (e.m.f) coefficient, electrical conductivity and common heat conductivity coefficients of the thermoelectrical branch materials respectively. In Eq.(1) δ_1 and δ_2 are the parameters containing the quantities of the elements in the thermoelement branch circuit (first stage) and control circuit (second stage) of TSC respectively. There R is the electrical resistance of the phase transition material, r is the load resistance and E is voltage of the control circuit and C is the capacitance created when the ferroelectric material used, and T is the working temperature of the thermoelement and is set according to the phase transition temperature of the material of the control unit.

3 Results

It is obvious from Eq.(1) that the maximum value of δ_1 which characterize the thermoelement circuit, is only possible by the optimization of the values of α, σ and H and the parameters they depend on . The optimization is done by using some approximation methods.

In the first approximation, the boundary conditions that mobility is independent of current carrying concentration and electron gas is not degenerate, $H_{\text{lattice}} >> H_{\text{electron}}$; ZT $\simeq$ 1, is assumed. Under this approximation , the following relations

$$\alpha_{\mathrm{opt}} = \frac{\mathrm{k}}{\mathrm{e}} = 86\mu\mathrm{V/K}$$

$$\mathrm{n_{opt}} = \frac{2(2\pi \mathrm{m^*kT})^{3/2}}{\mathrm{h^3}}\mathrm{e^{r+2}} \quad (3)$$

$$\delta_{1(\max)} = \mathrm{kT}\gamma\frac{2(2\pi \mathrm{m^*kT})^{3/2}}{\mathrm{h^3}}\frac{\mathrm{e^{r+2}}}{(1+\mathrm{ZT})}$$

for the materials of the thermoelement can be obtained [4], [5]. Here, m^* is the effective mass of current carriers, h and k are Planck and Boltzman constants respectively, r' is a parameter related to the mechanism of the scattering of current carriers. In equation (3) γ is defined as follows,

$$\gamma = \frac{\mu}{H_{lattice}} \left(\frac{m^*}{m_0}\right)^{\frac{3}{2}} \quad (4)$$

and is a coefficient related to the efficiency of matrix of the thermoelement branch materials. In Eq. (4) m_0 is the rest mass of electron and μ is mobility of current carriers. Calculations of $\delta_{1(max)}$ are also made below for $r' = 0$ case which is faced most in practice.

Using the approximation mentioned above, it can be said that the efficiency of the thermoelement in TSC and that in TEC is determined by the same γ parameter.

The optimum current carrier concentration and thermo e.m.f coefficient of TSC are considerably different from the corresponding TEC values. Optimum current carrier concentration has very high value in TSC. Because of this, electronic component of the heat conduction must be taken into consideration in these devices, and also the influence of degenerate electron gas on the thermoelectric parameters of the TSC materials must be taken into the account.

In the second approximation, with the consideration of the electronic contribution to the heat conduction, the thermo electromotor force (e.m.f) coefficient, α_1, was obtained as follows.

$$\alpha_1 = \frac{k}{e}(1 + C\gamma e^{\mu^*}) \quad (5)$$

Here μ^* is reduced chemical potential and C is defined by

$$C = LeT\frac{2(2\pi m^* kT)^{3/2}}{h^3} \quad (6)$$

where, L is Lorentz number. Graphical solutions of Eq.(5) are shown in Fig.1, for different γ values given in the same figure. It can be seen from Fig.1 that, the degeneration of the electronic gas does not affect the thermo e.m.f. coefficient, but it has large effect on the concentration.

In the third approximation, the electronic contribution to the heat conduction and degeneration of electron gas are taken into account together. The results of such approximations, namely, the variation of δ_1 with μ^* for the same γ_i, $(i = 1, 2, 3, 4, 5)$ values, given in Fig.1 , are shown in Fig.2 . There the curves are numbered according to the indices of γ_i . The 4 th and 5 th curves in Fig.2 show that δ_1 depend on μ^* weakly. This indicates that metals and metal alloys can be used together with the semiconductors in the thermoelement branches of the TSC.

In the experimental examination of the voltage amplification coefficient of the TSC, circuit materials of various type prepared by different methods were used. Namely, Bi_2Te_3 and Bi-Sb based solid alloys which works in the temperature range $\leq$ 600K; and alloys of $A^{IV}B^{VI}$ group elements with group III and rare earth elements which works between 600-900K; Ge-Si, silicite, carbide and their compounds with transition elements, and metal and metal alloys which works at temperatures larger than 900K have been used for this aim.

Our experimental results show that, with the proper selection of γ matrix and by the optimization of the carrier concentration, materials which make δ_1 maximum and can work at large temperature ranges, can be produced.

In the control circuit, δ_2, metal-semiconductor alloys, ferroelectric and magnetic materials with different phase transition temperature were used. Considering the physical properties of each control element, optimum voltage values corresponding to maximum values of δ_2 were determined.

The variation of the voltage amplification coefficient, β, with the input voltage ,V_i, is shown in Fig.3 . In Fig.3, the cases, for the materials with various positive thermal resistance coefficients such as barium titanate and alloys containing barium titanate are shown by the curves numbered as 1,2,3,4,5; and for those with negative thermal resistance coefficients such as Ti_2O_3 and VO_2 are shown by curves 6 and 7 respectively.

It can be seen from the experimental results in Fig.3 that for each of the optimum voltage value there is a corresponding maximum (optimum) value of β and at the voltage values different from the optimum value β decreases. β is strongly dependent on the physical properties of the control element, such as the variation of resistance with temperature, and it is limited by the resistance. Therefore working temperatue ranges at which the resistance of the control element varies linearly with temperature, should be chosen.

4 Conclusion

By selecting the thermoelement and the control circuit properly, it was possible to obtain important values such as $10^3 - 10^4$ for the voltage amplification coefficient, β, of TSA's.

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Figures

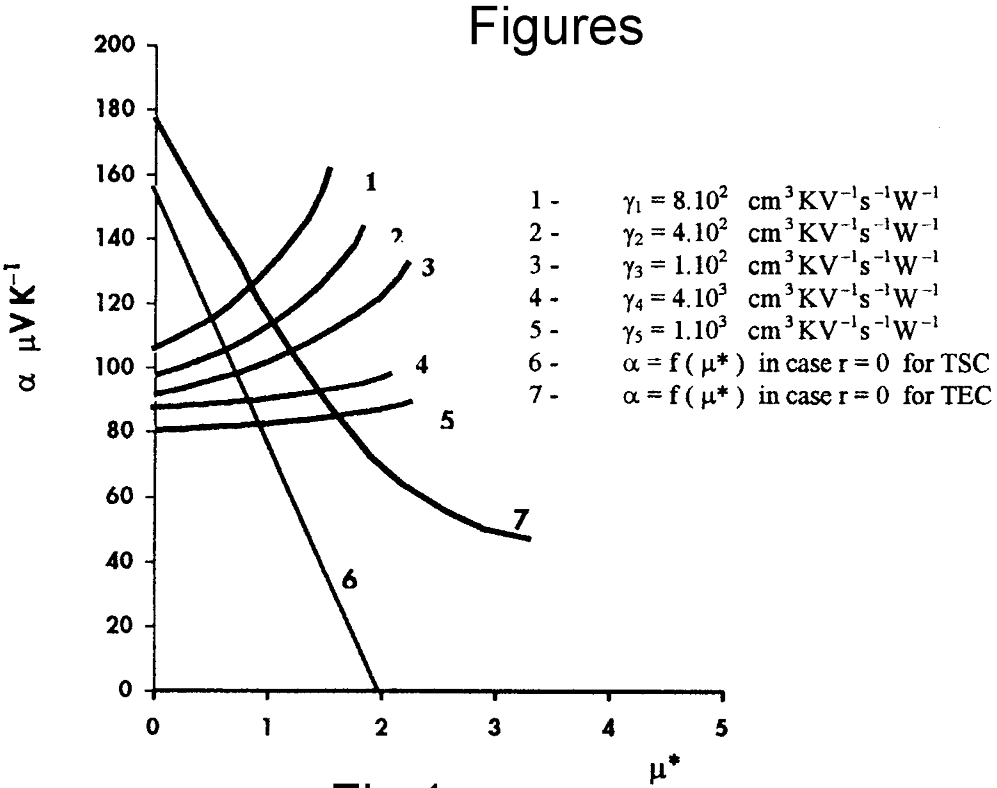

Fig.1

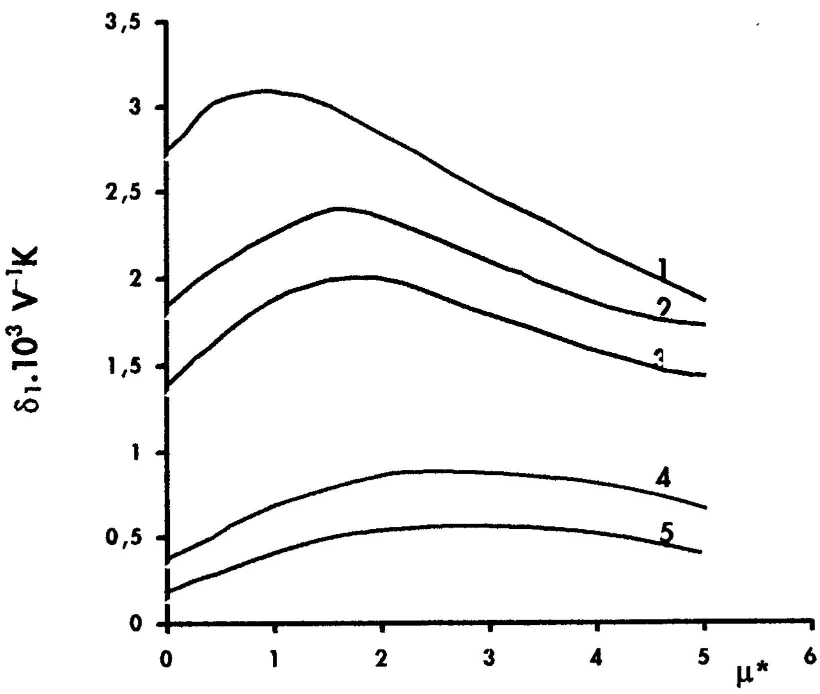

Fig.2

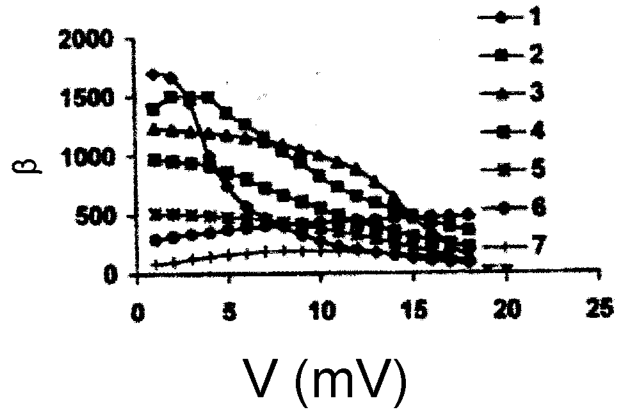

Fig.3