Scientific Notes of Taurida National V. I. Vernadsky University
Series : Physics and Mathematics Sciences. Volume 26 (65). 2013. No. 2. P. 138-142

UDK 537.6

INFLUENCE *S-D* EXCHANGE INTERACTION ON THE TRANSPORT PROCESSES IN THE FERRITES

Yevstafyev I. I.

Taurida National V. I. Vernadsky University, 4 Vernadsky Ave., Simferopol 95007, Ukraine
E-mail: ivan@crimea.com.ua

S-d exchange interaction energy is estimated in ferrite spinel from temperature dependencies in the region of Curie temperature and thermal EMF. Numerical values of *s-d* exchange integral are obtained. Value of the integral is in agreement with the estimations based on electric conductivity and thermal EMF.
Keywords: *s-d* exchange interaction, conductivity, thermal EMF.
PACS: 75.10. ± b

INTRODUCTION

Interaction between charge carriers and magnetic system is important feature of magnetic semiconductors. The most common parameter to characterize this interaction in the approximation of wide zones is the so-called *s-d* interaction integral I_{sd} [1]. The value of this parameter can be obtained from several experimental dependencies [2, 3, 4, 5]. In the present work four independent methods of estimation of *s-d* interaction integral were considered, as described below.

Experiments were conducted in single crystal $CdCr_2Se_4$, MnZn and NiZn ferrites.

1. S-D PARAMETER ESTIMATION BASED ON ANALYSIS OF IRREGULAR CONDUCTIVITY BEHAVIOR IN THE CURIE TEMPERATURE REGION

Let's consider irregular behavior of magnetic semiconductors in the Curie temperature region (T_c). In some magnetic semiconductors there is a region with negative value of $\frac{d\delta}{dT}$. For example in n-type $CdCr_2Se_4$ conductivity increases by several orders with the decrease of temperature from 150 K to 100 K [2]. In case of investigated ferrites this increase of conductivity is much lower, however, just like in n-type $CdCr_2Se_4$, the maximum value of $\frac{d\delta}{dT}$ is observed near T_c. In scope of exponential dependence of carriers' density on temperature, the mechanism of this phenomenon can be presented in the following way. Concentration of the carriers depends on the value of activation energy divided by thermal energy $\frac{\Delta Ea}{kT}$. In remote paramagnetic region where the activation energy weakly depends on temperature, this relation increases with temperature drop. Introduction of close magnetic order adds magnetic part ΔEm, the value of which depends on magnetization. Under magnetization we consider the sum of two members – local and volume magnetizations. If $T > T_c$ it is, mostly, local magnetization in the regions of near add-on states. Due to the indirect and modification *d-d* – exchange in the region of add-on center, the temperature of magnetic order formation is higher than T_c temperature of the crystal. That's why the rate of local magnetization change near T_c is low. Approaching the Tc what becomes determining contribution is the input of magnetization of the matrix. The matrixes arranged regions form in the fluctuations near the add-on states. The rate of change in this part of magnetization is much higher. All this leads to fast growth of magnetic contribution in the activation energy and the relation $\frac{\Delta \mathrm{E}a - \Delta \mathrm{E}m}{kT}$ can decrease with the temperature drop, which causes growth of the conductivity. It is clear that $\frac{dm}{dT}$ has its maximum in the vicinity T_c, therefore $\left|\frac{d\delta}{dT}\right|$ has maximum in this region too. Further from T_c the value of $\frac{dm}{dT}$ decreases, which near certain temperature again causes drop of conductivity with temperature drop. In case there is a thermal dependence of the magnetization region $\frac{d\delta}{dT} < 0$ two special points must exist, where $\frac{d\delta_{1,2}}{dT} = 0$. Point T_1 lays above T_c and is related to change of magnetic contribution as a result of the growth of fluctuation regions of magnetization. Second point T_2 is connected with the slowdown of magnetization change rate when $T < T_c$. Let's analyze possible values of T_1 and T_2 considering that concentrational mechanisms and $\Delta \mathrm{E}m = \frac{1}{2} ISm(T)$ are responsible for the irregularity. In this case we conclude that $\frac{d\delta}{dT} = \delta(T)\left(\frac{Ea - \Delta \mathrm{E}m}{kT^2} + \frac{1}{kT} \cdot \frac{d\Delta \mathrm{E}m}{dT}\right)$, as $\delta(T) \neq 0,$ th condition $\frac{d\delta}{dT} = 0$ can be written as:

$$\mathrm{E}a - (\Delta \mathrm{E}m - \frac{d\Delta \mathrm{E}m}{dT} \cdot T) = 0 \qquad (1)$$

$$\text{и } \mathrm{E}a - \frac{1}{2} IS(m(T) - \frac{dm(T)}{dT} \cdot T) = 0 \qquad (2)$$

Equation (2) can be used if $T < T_c$ in the point T_2 for independent determination of *s-d* exchange parameter because temperature dependence of matrix magnetization in FM region is obtained experimentally.

Appearance of conductivity irregularity in the T_c region depends on several parameters of magnetic semiconductor. When the difference (2) is negative, increase of conductivity is observed as the temperature drops; when it is negative normal semiconductor dependence is registered. However usually in ferrites the second term is small and there are no $\frac{d\delta}{dT} < 0$ observed in temperature dependence of conductivity. Metallic type of conductivity can be observed in case of small activation energy E_a (compared to second term) in the region of magnetic order. Let's consider this irregularity on the dependence of conductivity on temperature in $Mn-Zn$ ferrite (Fig. 1).

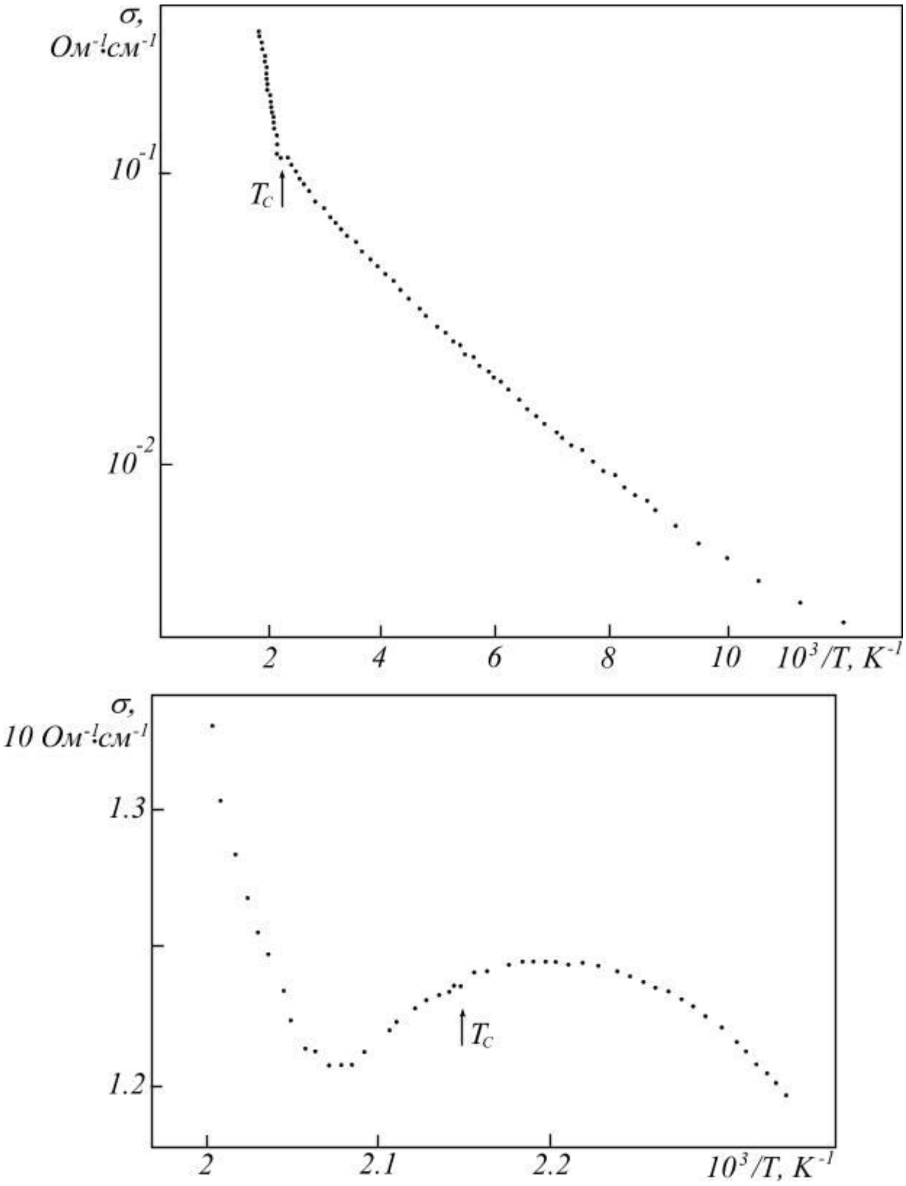

Fig. 1. Dependence of conductivity on temperature in $Mn-Zn$ ferrite.

The value $\frac{d\delta}{dT}=0$ is observed when T = 452 K. At this temperature from magnetic measurements $\frac{dm}{dT}\sim 5\cdot 10^{-3}\,K^{-1}$, $\frac{m(T)}{m(0)}\approx 0{,}08$, activation energy in paramagnetic region $Ea=0{,}26eV$. Introducing these values in equation (2), we obtain for $I_{sd}\approx 0{,}1eV$, which is in good agreement with the values obtained for this ferrite using method (4) (E_d = 0,11 эВ) and is independent confirmation of correct calculation of *s-d* exchange parameter value. As the value $\frac{dm}{dT}$ decreases going away from T_c, the region $\frac{d\delta}{dT}<0$ for this ferrite is determined by the value I_{s-2}.

2. ESTIMATION OF *S-D* INTERACTION INPUT IN THERMO EMF

Following [3] the relation between two macroscopic parameters of a material: thermo EMF coefficient Q and electric conductivity σ can be presented as:

$$Q=-\frac{k_0}{e}\left\{\frac{T}{\rho}\frac{\delta\rho}{\delta T}+\frac{I_{sd}}{2K_0}\frac{\delta M}{\delta T}\right\}, \quad (3)$$

where $M=M_{sd}+M_{dd}$, M_{sd} is normalized magnetization determined by *s-d* exchange, M_{dd} is determined by d-d exchange that arises when $T\le T_c$; ρ is reversed conductivity.

We can conclude from the formula (3) that in magnetic nondegenerate semiconductors experimental study of thermal EMF allows determining temperature dependence of *s-d* exchange interaction energy. As the energy of *s-d* exchange interaction is usually an order more than the one of *d-d* exchange interaction, the near order in the regions of add-on centers exists in the temperatures considerably higher than Curie temperature. It permits analysis of *s-d* exchange parameter dependence on temperature using the information of d-matrix magnetization.

We have analyzed possibility to apply this approach for $Mn-Zn$ ferrites using the values of thermal EMF from [3,6]. The value $I_{sd}\approx 0.3$ eV in the temperature range T (80 - 110) K. The value is in agreement with the results obtained in [6].

CONCLUSION

Results of the research confirm applicability of wideband approach when considering kinetic effects in the researched substances. Obtained values of *s-d* exchange parameter allow determining the level of interaction of electric and magnetic subsystems in the considered materials and separate inputs of other effects in the transport processes.

References

1. S. V. Vonsovsky, *Magnetism* (Nauka, Moscow, 1971).
2. V. N. Berzhansky, V. K. Chernov, “Carrier transfer processes in the magnetic semiconductors $CdCr_2Se_4$,” in *Magnetic semiconductors and their properties* (Physics institute SO AS USSR, Krasnoyarsk, 1980).
3. I. I. Zyat’kov, V. P. Miroshkin, E. A. Popova, *Works of Leningrad electrotechnical institute of V. I. Ulyanov*, 104 (1985).
4. I. I. Yevstafyev, in *Abstracts of International Conference “Functional Materials” ICFM’2011* (Simferopol, 2011).
5. I. I. Yevstafyev, in *Proceedings of International Conference “Electrotechnical materials and components (ICEMC-2013)*” (Crimea, Alushta, 2013).
6. I. I. Zyat’kov, V. P. Miroshkin, Ya. I. Panova, *USSR AS News. Non organic materials* **21**, No. 12, 2096 (1985).

Евстаф’ев І. І. *S-d* – обмінна взаємодія в ферритах і її вплив на процеси переносу / І. І. Евстаф’ев // Вчені записки Таврійського національного університету імені В. І. Вернадського. Серія : Фізико-математичні науки. – 2013. – Т. 26 (65), № 2. – С. 138-142.

Проведена оцінка енергії *s-d* обмінного взаємодії в ферритах шпинелях з температурних залежностей провідності в районі температури Кюрі і термоедс. Отримано чисельні значення інтеграла *s-d* обміну. Величина інтеграла узгоджується з оцінками з даних по електропровідності і термоэдс.

Ключові слова: s-d обмінна взаємодія, провідність, термоедс.

Евстафьев И. И. *S-d* – обменное взаимодействие в ферритах и его влияние на процессы переноса / И. И. Евстафьев // Ученые записки Таврического национального университета имени В. И. Вернадского. Серия : Физико-математические науки. – 2013. – Т. 26 (65), № 2. – С. 138-142.

Проведена оценка энергии *s-d* обменного взаимодействия в ферритах шпинелях из температурных зависимостей проводимости в районе температуры Кюри и термоэдс. Получены численные значения интеграла *s-d* обмена. Величина интеграла согласуется с оценками из данных по электропроводности и термоэдс.

Ключевые слова: s-d обменное взаимодействие, проводимость, термоэдс.

Список литературы

1. Вонсовский С. В. Магнетизм / С. В. Вонсовский. – М. : Наука, 1971. – 1032 с.
2. Бержанский В. Н. Процессы переноса носителей заряда в магнитных полупроводниках $CdCr_2Se_4$/ В. Н. Бержанский, В. К. Чернов // Магнитные полупроводники и их свойства. – Красноярск : Институт физики СО АН СССР, 1980. – С. 44-73.
3. Зятьков И. И. Исследование термоэдс и проводимости Mn-Zn ферритов / И. И. Зятьков, В. П. Мирошкин, Е. А. Попова // Работы Ленинградского электротехнического института имени В. И. Ульянова. – 1985. – С. 104-108.
4. Yevstafyev I. I. Thermoelectric properties of the ferrites with local angular spin structure / I. I. Yevstafyev // International Conference “Functional Materials” ICFM’2011, Partenit, October 3–8, 2011 : Abstracts. – Simferopol, 2011. – P. 124.
5. Yevstafyev I. I. Influence of s-d exchange interaction on the transport processes in ferrite spinels / I. I. Yevstafyev // International Conference “Electrotechnical materials and components (ICEMC-2013)”, Crimea, Alushta, 2013 : Proceedings.
6. Зятьков И. И. Проводимость монокристаллов ферритов Mn-Zn / И. И. Зятьков, В. П. Мирошкин, Я. И. Панова // Новости АН СССР. Неорганические материалы. – 1985. – Т. 21, № 12. – С. 2096-2098.

Received 30 May 2013.