Letters in High Energy Physics Volume 2024
ISSN: 2632-2714

Thermo-emf Granular Metal-Dielectric Composites: Fe(Al2O3), Fe(Nb2O3), Ni(Al2O3), and Ni(Nb2O3)

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Abstract

One of the most interesting aspects of ferromagnet-dielectric composites is their thermoelectric properties. It is commonly known that thermoelectric devices require high conductivity at low thermal conductivity; these properties can be attained in metal-insulator nanocomposites with particular phase relationships and compositions.

Keywords- Thermo-emf Granular, Metal-Dielectric Composites

Introduction

In granular systems, the thermoelectric figure of merit is estimated to be larger than unity [1]. However, there is little information available on the composition-dependent thermoelectric emf because it is difficult to produce materials across a broad range of metallic phase concentrations. The results of research are typically achieved based on limited quantities of samples, rarely exceeding three, which differ in composition. It therefore limits the possibility to draw decisive conclusions about the nature of the dependence of thermo-emf on concentration. Additionally, it denies the possibility to assess completely the full effect of the phase composition and structural characteristics on that relationship. This implies that the information which is obtained from those investigations may not be enough to explain the complex relationship between those factors and their general contribution to the thermo-emf behavior of the investigated materials.

The thermo-emf (S) value in systems that are past the percolation threshold typically has a tiny value and is not greatly affected by variations in x. An investigation into Cu (SiO2) thin-film nanocomposites with copper contents ranging from 0.434 to 1.0 confirms the idea put out by Bergman and Levy [3, 4] that S stays rather constant above the percolation threshold.

Based on the available data, the thermo-emf drops as metal concentration drops (below 0.43), indicating that pre-percolation samples typically have lower thermo-emf values than samples that have higher percolation thresholds. Comparable results are seen in other works [5,6], where different samples of the Co-Al-O systems, namely SP-TN (placed above the threshold of percolation), SP-IM (at the proximity of the threshold), and SP-MT (below the threshold) showed different thermo-emf values at the room temperature. In the experiment it can be clearly seen that sample of SP-TN has a thermo-emf value of around 8 μV/K indicating a less sensitiveness compared to the other samples. The SP-IM sample, positioned near the percolation threshold, shows a slightly higher value for the thermo-emf of about 11 μV/K. Meanwhile, the SP-MT sample placed below the threshold presents the highest thermo-emf value at about 12 μV/K. This evolution of the values of the thermo-emf in these three samples shows how performance in thermoelectricity is highly dependent upon the positioning with regard to the percolation threshold.

Other research, however, suggests that thermoelectric power rises as grain size decreases

[7, 8]. Theoretical calculation is considered to suggest that in dielectric region, values of thermo-emf are thought to be higher than that measured in high metal concentration areas due to the decrease in metal concentration coupled with the decreased grain size. The lowering of the metal concentration increases the scope for electron mobility together with charge transport within the dielectric phase due to the associated increase in grain size decrease. This leads to higher thermo-emf values in the dielectric regions compared to the regions that have a relatively high density of metallic constituents where concentration and grain size work against the thermoelectric performance. Overall, the absolute values and signs of thermo-emf values in different granular systems differ considerably. Some typical values are shown in the table.

Table (1): Thermo-emf nanocomposites at room temperature.

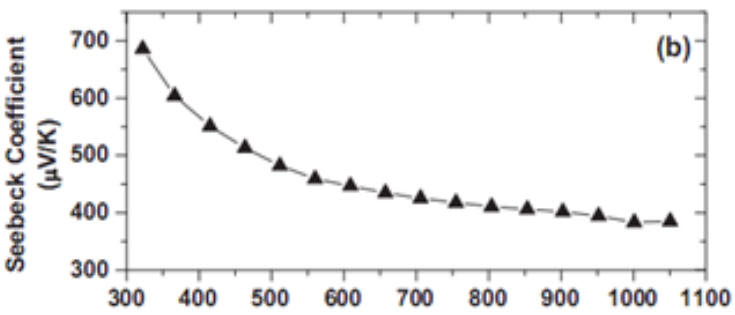
№	Composite	Thermo-emf at room temperature, μV / K
1	$Cu(SiO_2)$	- 1-2 [2]
2	$Co_{20}Ag_{80}$	- 6,2 [9]
4	$Fe_{28}Ag_{72}$	- 11,5 [10]
3	$Co_{20}Ag_{80}$	- 12,5 [11]
5	Co-Al-O	- 8-12 [5]
6	$Co_{42}Ag_{58}$	- 16,5 [12]
7	$Fe_{27}Cu_{73}$	- 21 [10]
8	$Cu\text{-}AlO_2$	0,7 [13,14]

Based on the data in the table and the results of [15], it can be concluded that nanocomposites containing ferromagnetic metal granules have greater thermo-emf values compared to those containing non-ferromagnetic metal granules. The metal composites have the most noteworthy thermo-emf values. The table shows that the general indication of the thermo-emf of nanocomposites is negative. This would suggest that the thermo-EMF sign of the individual components within the granule is not driving the thermo-EMF sign of the composite. One makes this point especially when the composite has reached ambient temperature; in this case, other properties may drive the thermoelectric behavior of the composite as a whole. As such, the thermal and electrical interactions inside the composite may lead to a phenomenon where the manifestation of the thermo-EMF appears as reversed as that expected with each component. μV / K, Fe ≈ + 11 μV / K, Cu ≈ + 2.5 μV / K [16]).

Temperature Effects on Thermo-EMF in Nanocomposites

We have studied the metal-dielectric interface and temperature dependence of thermo-emf for nanocomposites prepared at various synthesis stages. It is usually found in most studies concerned with the temperature dependence of thermoelectric power that the researchers consider either relatively low temperatures (77-300 K) or rather high temperatures (300-900 K). Such selection complicates drawing generally valid conclusions or identification of the roles played by dopants and the matrix in the thermoelectric power. It does, however, enable comparison of results for those ranges of temperatures.

Cu-AlO2 composites prepared in a variety of ways were investigated in [14,17, 18]. According to [14], as temperature rises across the studied span, the Cu-AlO2 composite's resistance and the amplitude of the thermoelectric power decrease while the power factor rises. (Figure 1).



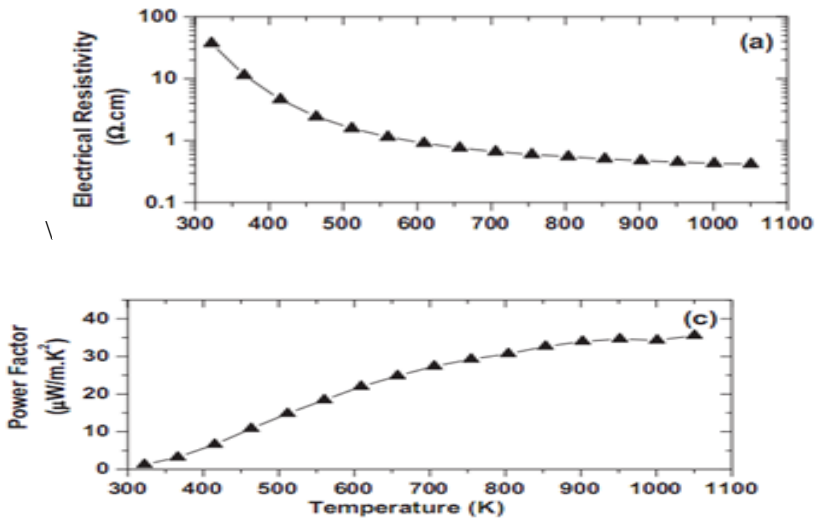


Fig. (1); Temperature Dependence of Cu-Al_2O_3 Composites: (a) Resistance, (b) Thermo-EMF, and (c) Power Factor (c) [14].

distance of 40 mm. The results are shown in Figures 2 and 3. It is common for metal-insulator composites to have absolute thermo-emf values between 8 and 9 V/K [2, 5]. Similar to the charge carriers' (electron's) sign, the sign is negative. In homogeneous materials, the thermo-emf magnitude remains constant while the direction of heat flow varies (Fig. 2). Given that the samples' shape and composition remain constant along their entire length and that the charge transfer mechanisms through granular media are insensitive to changes in the gradient's direction, this conclusion is evident.

Thermo-EMF Measurement in Homogeneous and Concentration-Gradient Fe (Al2O3) Samples

For thermal-electromotive force measurements, samples at identical concentration were employed. The measurements using the hot probe technique were also conducted as "forward" and "reverse" to every measurement. In the side opposite to the "hot" probe of the sample, the area was heated to a temperature of 373 K, and the other side was cooled at ambient temperature of 295 K. This established a temperature gradient of 78°C over a

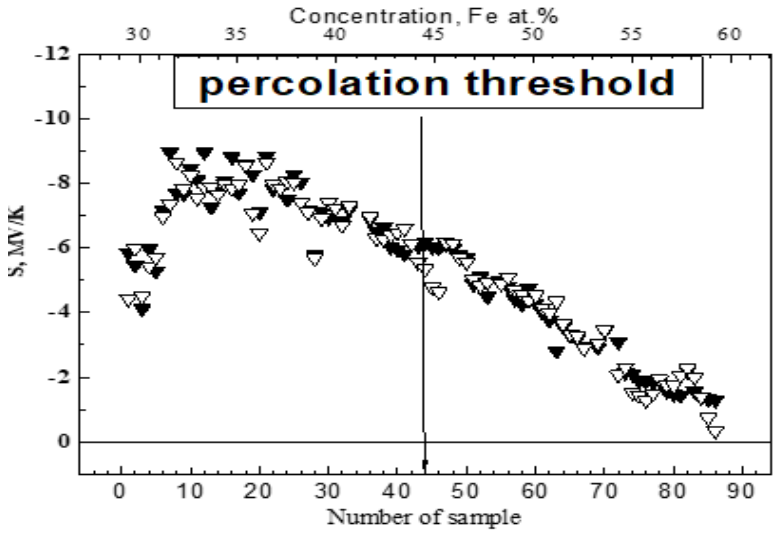
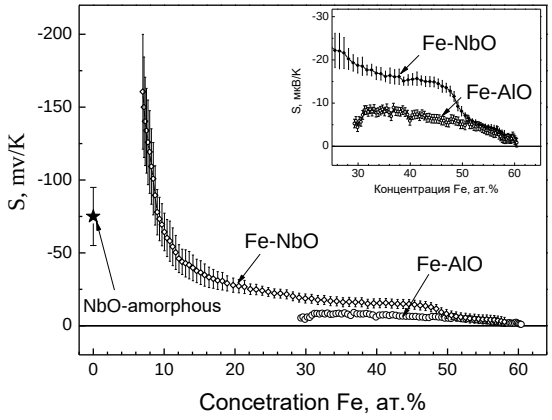


Fig. (2) In homogeneous Fe (Al_2O_3) samples, thermo-EMF varies by sample, with distinct symbols representing heat flow directions.

While inspecting focus angle tests, it was tracked down that the worth of thermo-emf relied upon the bearing of the intensity motion (Fig. 5.9). At the point when the intensity transition is guided from the high-opposition edge to the low-obstruction edge, as outlined in Figure 5.9, the worth of the outright thermo-emf for tests with nuclear numbers somewhere in the range of 35 and 55 is 3-4 V/K higher. At the end of the day, the thermo-emf increments as the pre-permeation zone gets warmed and the charge transporters move from that area to the piece of the composite where metallic conductivity is more conspicuous by passing the permeation boundary. The other way of the intensity motion, S has a lower esteem (see Fig. 5.9).



Influence of Composite Matrix Material on the Thermoelectric Effect

The overall advantages of the thermoelectric effect of pure components and the thermal resistance of each phase determine the magnitude of the thermoelectric effect in the composite medium. Large differences in the thermal resistance of these oxides, that is, clear differences in the size of the thermo-emf, are quite legitimate to expect since the conductivity of the niobium oxide matrix exceeds that of the alumina matrix by many times.

Fig. (3) is a diagram of a Thermo-emf of Fe-Al_2O_3 and Fe-Nb_2O_3 Composites

Experiments were conducted to validate this theory. The "hot probe," which has a 40 mm length

Peak values of thermo-emf occur in the pre-permeation zone, which corresponds to the best balance of thermal resistances over the distinct phases appearing within the composite material. This peak represents a state where interaction of all components of the composite leads to fully transferring thermal energy from the source towards its point of consumption and increases the thermoelectric performance thereof. This optimal condition is contributed by the alignment of thermal resistances among the phases, thus pointing out the role of phase interaction in maximizing the thermoelectric material properties. This phenomenon makes optimization of composite design important to realize high-quality thermoelectric behavior. The maximum corresponds to a balance favoring the heat transfer; therefore, the complex interplay of the material phases involved in this action is pointed out. This means that, overall thermoelectric response is heavily influenced by relative thermal resistances; therefore, there might be deep knowledge pertinent to optimizing thermoelectric efficiency about the interactions of the phases at this very zone, W_{met} and W_{diel}, with the corresponding thermo-emf values for the metallic and dielectric phases, S_{met} and S_{diel}. This is based on the premise that the thermo-emf of the composite medium can be represented as follows: The prepermeation structure of the composite should be seen as a set of guides with distinct S and W values in accordance with Kohler's rule.

$$S = \frac{S^{мет.}W^{мет.} + S^{Die.}W^{Die.}}{W^{мет.} + W^{Die.}}.$$

The values of thermo-emf for composites that contain a niobium oxide network reach as high as 150-180 V/K at low metal concentrations, which is significantly greater than that characteristic of a typical metal-dielectric system. Such significant enhancement in the thermo-emf may be considered an indication of the potential of niobium oxide networks in optimizing thermoelectric properties. The appearance of high values of thermo-emf at low metal concentrations shows that composites can offer performance better than the metal itself in such applications, which appeals for further research into mechanisms of action and practical applications [2, 5]. Unadulterated shapeless niobium oxide can be made with high thermoelectric power by faltering. Figs. 4 and 5 presentation the thermo-emf values estimated on undefined niobium oxide tests, which appear to be slender movies developed on silicon substrates.

The thermo-emf of composites containing a niobium oxide network approaches 150-180 V/K at low metal focuses, which is essentially higher (by a significant degree) than the qualities normally saw in composite metal-cover frameworks [2, 5]. Unadulterated indistinct niobium oxide can be made with high thermoelectric power by faltering. Figs. 4 and 5 presentation the thermo-emf values estimated on formless niobium oxide tests, which appear to be dainty movies developed on silicon substrates.

In composites including a niobium oxide grid, it is basic that the metal stage appears as nanogranules rather than disintegrated metal particles inside the nebulous niobium oxide volume. Figures 4 and 5 actually demonstrate a monotonic dependence of S on the sample, without signs of subjective changes in it, and corresponds to a tendency toward a more homogeneous structure. This makes the observed variations not caused by qualitative shifts but by a quantitative change of the morphology of composites. In particular, for lower concentrations of metal, the decrease in granular size is anticipated to accompany a composite with a more uniform morphology.

A small concentration of metal seems to act as an electron reservoir that may tunnel out from the granules into the more confined states within the oxides. Heating the environment about the composite enables the rapid filling up of free and a 78 degree temperature gradient, was utilised to measure thermo-emf. Figs. 4 and 5 display the concentration dependences of thermo-emf composites with distinct dielectric matrix materials but the same metallic phase. Regardless of the metallic phase material, it is obvious that replacing alumina with niobium oxide increases the specific thermo-emf.

The dependence plot, for which the inset displays the concentration. The metal phase is the same in both systems.

Further, it is an undeniable fact that the role of sulfur in oxide state varied composites is similar to the role it plays in the structure of a metal medium with directed ordering when the accentuation is made on the metal stage. Such behavior is characteristic for composites containing more than 50% of iron and more than 60% of nickel. In niobium oxide composites, the thermo-emf increases with lowering of metal concentration to approximately 25-30 atomic percent, regardless of the fundamental structure of the metal stage. As such, this increase is several times greater than that exhibited in alumina composites (see Figures 3 and 4).

In composites with a niobium oxide network, as the concentration of metal decreases, the thermo-emf values have significantly increased. This steep rise in thermo-emf occurs coincidentally with the threshold of electrical permeability and is, therefore, associated with the appropriate concentration range of the metallic phase. In this concentration range, it actually undergoes a sharp phase transition that rapidly results in an enhancement of thermal EMF. For composites Fe (Nb2O3), these focuses range from 15 to 18 at. percent Fe (see Figure 4). In this framework, the electric permeation limit is 14 at. percent Fe. The electric permeation limit in the framework is 30 at. percent Ni, and the 100-x limit focus for composites Ni (Nb2O3) is 30-35 at. percent Nb (Figure 5). The increase in thermo-emf during the transition over the electric limit of permeation is not observed in any of the composite frameworks containing an aluminium oxide grid (the Fe (Al2O3) 100-x framework, Fig. 4; the Ni (Al2O3) framework, Fig. 5).

conductivity of the composite not entirely set in stone by conduction electrons moving along a consistent metallic medium. This is on the grounds that an expansion in the metal stage fixation in this creation district doesn't suggest an adjustment of the electromigration component. Figure (4) shows a three-layered object graph. Ni (Al2O3) and Ni (Nb2O3) composites have focus subordinate explicit thermo-emfs.

restricted states with electrons in the forbidden zone of the oxide. The reason behind this is that the granules' nanoscale size enables electrons to tunnel from them to the lattice's defects. [20, 21, 22].

An article's three-layered graph can be found past Fig. (3). Fixation influences the particular thermo-emf of Fe (Al2O3) and Fe (Nb2O3) composites. The greatness of the thermo-emf is less subject to focus at the permeation limit, where the warm

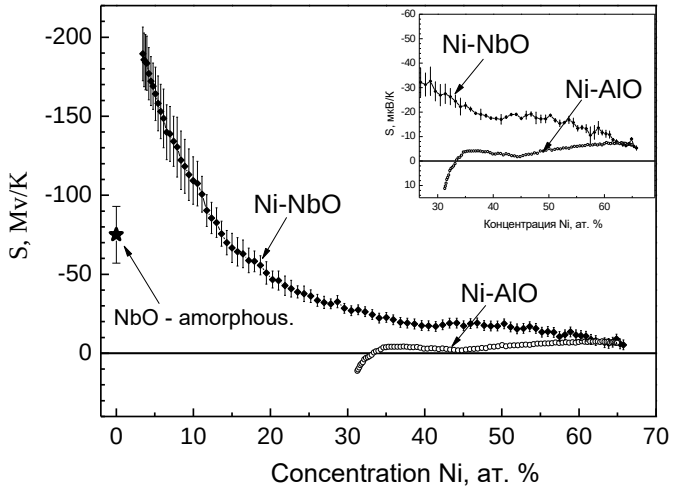


Figure (4). Ni (Nb_2O_3) and Ni (Al_2O_3) composites have a concentration-dependent specific thermo-emf. In the two systems, the concentrations of the metal phases are equal, as seen in the plot of dependency in the inset.

However, thermo-emf measurements of composites with the same dielectric matrix Fe (Al2O3) and Ni (Al2O3) reveal that the values are almost equal, suggesting that the dielectric matrix (Al2O3), as shown in figure (5), has a major influence and is not dependent on the metal part.

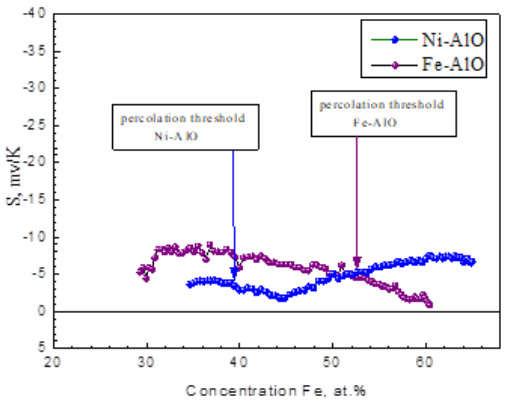


Fig. (5): Thermo-emf composites Ni (Al_2O_3) and Fe (Al_2O_3) are concentration dependent.

Conclusion

Subsequently, the thickness of involved electronic states in the oxide's band hole is more prominent in the warmed piece of the composite than exposed. Expressed in any case, the electrons got by the snares have a fixation slope on the off chance that the composite has a temperature slope. Because of the great conductivity of the niobium oxide lattice, electrons can move by means of the "jumping" system to the cool locale of the composite, which brings about charge rearrangement and the formation of the potential contrast that was seen during the investigation.

The overall thermal conductivity of the composite increases with an increase in the concentration of the metallic phase, which lowers the temperature gradient and, consequently, the thermo-emf values (Figures 4, 5).

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