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IMPACT OF AMORPHIZATION ON CRITICAL TEMPERATURE OF FERROMAGNET

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Abstract: In solid state physics, the issue of ferromagnetism and magnetism in general, in structured amorphous materials, attracted great interest in recent years, both in theoretical and experimental research. It is known that the crystal and the amorphous structure of the same substance do not have the same characteristics. Amorphous magnets constitute a class of systems with the highest degree of disorder. The existence of ferromagnetism in amorphous materials is determined by the relation between exchange interactions and configuration of magnetic atoms. In the computer experiments presented in this paper, the general-purpose software Maple was used, as well as a simplified Ising model, which implies that it is a ferromagnetic with a small impact of anti-ferromagnetic state. In this paper the effect of amorphization on critical temperature of ferromagnet is presented. The change of spontaneous magnetization depending on the temperature is observed, in a temperature range close to the critical temperature, and a critical temperature shift for different influences of nonhomogeneity of the interaction energy. The results are compared with results of other authors who deal with the same subject matter.
Keywords: ferromagnetism, critical temperature, amorphization.

1. INTRODUCTION

In general, magnetic materials can be divided into three groups: diamagnetic, paramagnetic and ferromagnetic materials. Diamagnetic materials are materials in which the magnetic permeability is slightly less than the permeability of vacuum and $\mu_r < 1$, since the internal magnetic field opposes the outside field.

Paramagnetic materials are materials in which the magnetic permeability is slightly greater than the permeability of vacuum $\mu_r > 1$, because the internal magnetic field coincides with the outside field.

Both of these groups of materials, which do not have significant application for the construction of magnetic circuits, are referred to as non-magnetic materials, since in these materials $\mu \approx \mu_o$. Ferromagnetic materials, which construct the group of magnetic materials, are used for magnetic construction of, for example, cars in which the magnetic permeability is substantially greater than the permeability of vacuum respectively μ_r »1 (from a few thousand to several hundred thousand). It is assumed that the increase in internal fields contribute to the field within the ferromagnetic material, and constitute so-called domains. Within the ferromagnet, the domains are chaotically arranged, which is why these materials are not permanent magnets. When these materials are found in the external magnetic field, it leads to the spontaneous orientation of their magnetic domains in the direction of the field.

At high enough temperature ferromagnetic material loses its ferromagnetic properties. Domains are then pulled down, and ferromagnetic material becomes paramagnetic. The temperature at which they lose ferromagnetic properties is called the Curie point.

The current interest in magnetism and the abundance of activities in this field are based on a few unifying aspects. The phenomenon of cooperative magnetic order in bulk materials is one of the most important branches of statistical physics in general and critical phenomena in particular [1−3]. The reason for this outstanding role of magnetism is given by the fact that predictions about universal properties of complex systems require information about the spatial dimensionality, as well as the symmetry of the interaction. Magnetic model systems provide an easy access to these parameters and represent the pioneers in the physics of critical phenomena [4].

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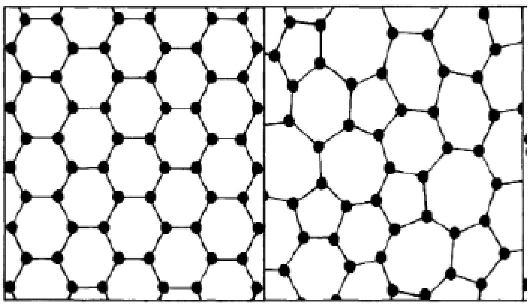
Amorphous magnets constitute a class of systems with the highest level of disorder. It should be noted that amorphous and disordered do not have the same meaning. Amorphous refers to the lack of a crystalline lattice. However, not all disordered magnets are amorphous. There are also disordered crystalline alloys [5]. One of the characteristic features of amorphous magnets is that some of the crystalline materials with an antiferromagnetic spin arrangement become ferromagnetic in the amorphous state.

2. MODEL

Amorphous materials are a class of solid materials whose main characteristic is the lack of a regulated arrangement of the atoms in the distance [6]. From the point of view of atomic structure, amorphous substances are analogous to liquids. Amorphous substances are characterized with the lack of regulation of distance in arrangement of the atoms and with existence of proper arrangement of atoms in close proximity. Figure 1 presents the arrangement of atoms in their equilibrium configuration, the small crystal (Figure 1a) and an amorphous substance (Figure 1b).



(a) (b)

Figure 1. Schematic representation of the atomic arrangement in (a) the solid crystal and (b) an amorphous system

Amorphous, like crystalline state, is characterized by a high degree of local correlations. The atoms are located at approximately the same distance, and the angles between them are almost the same, as a result of existence of chemical bonds that hold atoms together in solid systems. One way of obtaining amorphous alloy is rapidly cooling liquid metals, alloys or their vapors in order to obtain non-equilibrium conditions. It is important that the term amorphous substance defines any solid system with no periodicity at the atomic level. Adding different metalloid amorphous alloys Fe, or changing their initial composition, can influence the improvement of properties of alloys, both mechanical and electric, or magnetic. It is also important to note that the stability of amorphous alloy significantly changes in heat treatment if certain elements are added.

The Ising model is concerned with the physics of phase transition which occurs when a small change in parameter, such as temperature or pressure, causes large scale qualitative change in state of a system. One purpose of the Ising model is to explain how short-range interactions between molecules in a crystal give rise to long–range, correlative behavior, and to predict in some sense the potential for a phase transition [7,8]. Ising model has a combinatorial interpretation which is powerful enough in itself to establish some of the basic results concerning phase transitions.

In our computer experiments, a simplistic Ising model was used. It is assumed that the magnetization is

$$M = \frac{\sum_i M_i e^{-E_i / kT}}{\sum_i e^{-E_i / kT}} \tag{1}$$

and M_i and E_i are given by

$$M_i = \frac{1}{N^2} \sum_{j,n} S_{i,j,n} \tag{2}$$

$$E_i = -\sum_{j,n} \left(\varepsilon_{j,n} S_{i,j,n} S_{i,j,n+1} + \varepsilon_{j,n} S_{i,j,n} S_{i,j+1.n} \right) \tag{3}$$

$$\varepsilon_{j,n} = \varepsilon \left[1 + \alpha \cdot rand(-1,1)_{j,n} \right] \tag{4}$$

where α is non-homogeneity and *rand* $(-1, 1)_{j,n}$ is random number between -1 and 1.

List of symbols

$S_{i,j,n} = \pm 1$ magnetic dipole moment at position *(j,n)*

M_i − value of the magnetization in the ith configuration

E_i − energy of that configuration

ε − energy of interaction

In the applied approximate mode, random orientation of spins was generated in two dimensions, *j* and *n*. The value of spin (± 1), a lattice position *j* and *n*, and its contribution to the magnetization is calculated by averaging, i.e., divided into N^2. In this way, it takes into consideration the current average value of the magnetization. Averaging can serve to reduce the impact of randomly generated spins configuration, and thus reduce the error.

The program that is used in those experiments does not match the original Ising model, which is very far from reality, too, but makes it possible to obtain meaningful results. It used random 2000 configurations that are equally probable. Then the correction was performed by multiplying M_i the appropriate statistical weight (Boltzmann distribution) [9]. The magnetization of 1 or about 1 is thus practically excluded. It is conceivable that it is closer to reality than the original Ising model. It is unlikely that dipoles in a realistic structure have perfectly parallel set without the outside field,

4. RESULTS

Our results of the influence of non-homogeneity energy interactions on temperature phase transition are presented in this section.

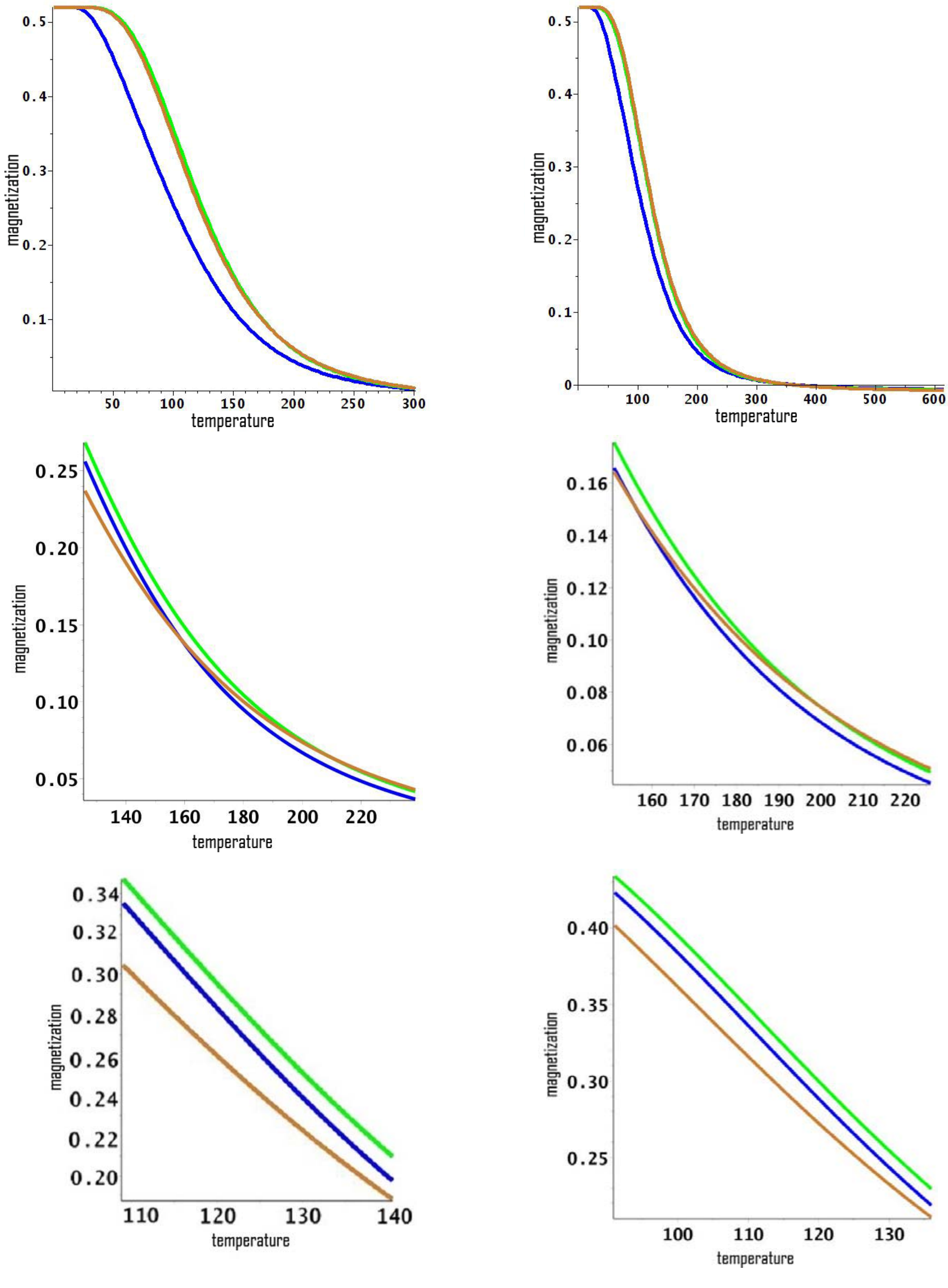


Figure 2. a) Non-homogeneity : 0.0 (blue line), 0.5 (green line), 0.85 (gold line),
b) Inhomogeneity: 0.05 (blue line), 0.4 (green line), 0.75 (gold line), Here : N=5, $\varepsilon = 70k$

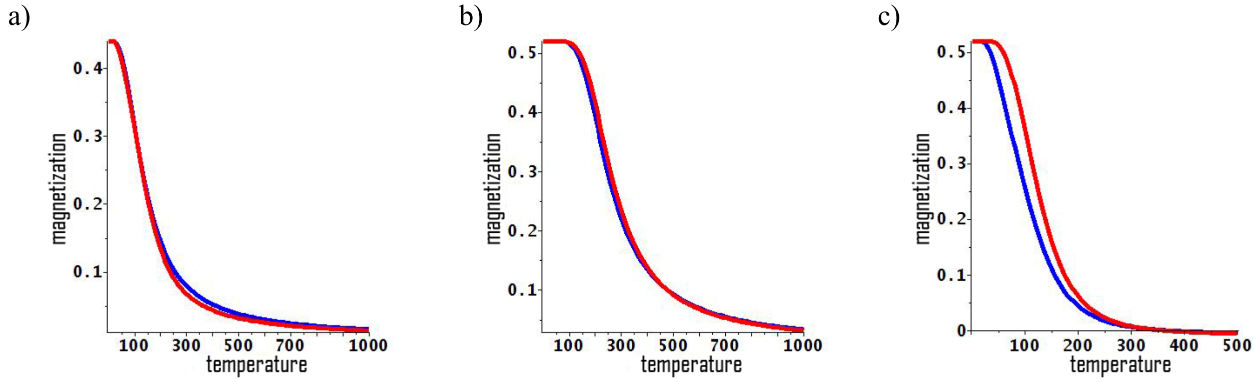


Figure 3. Non-homogeneity: 0 (blue line), 0.6 (red line), N =5 a) the number of configuration 50, b) the number of configuration 100, c) the number of configuration 1000

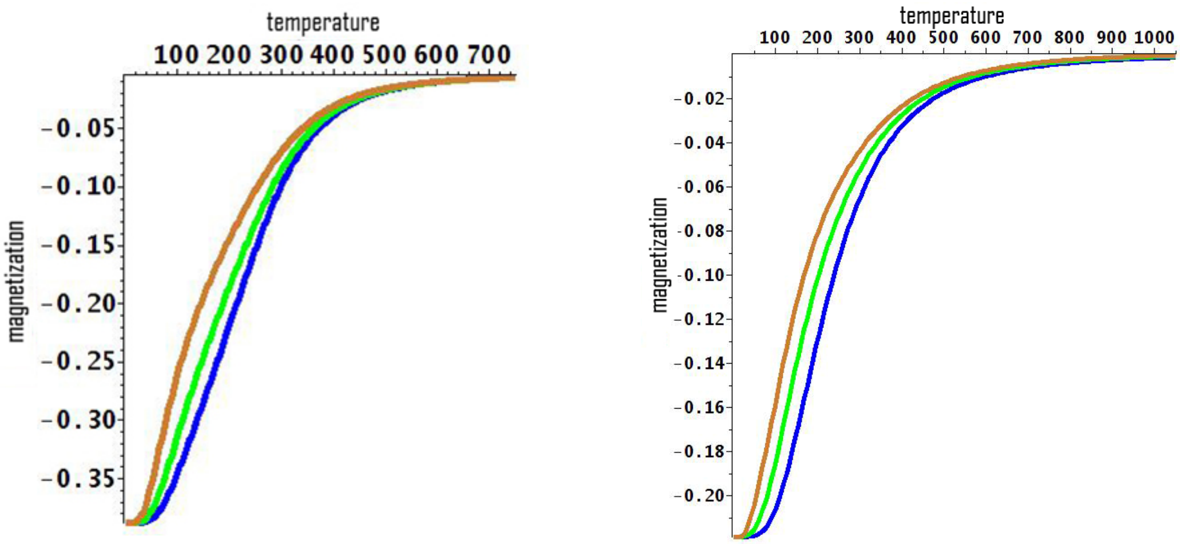


Figure 4. a) Non-homogeneity: 0.0 (blue line), 0.2 (green line), 0.4(gold line), N=7, the number of configuration 1000, b) 0.65 (blue line), 0.8 (green line), 0.9 (gold line). Here: N=8, the number of configuration 1300

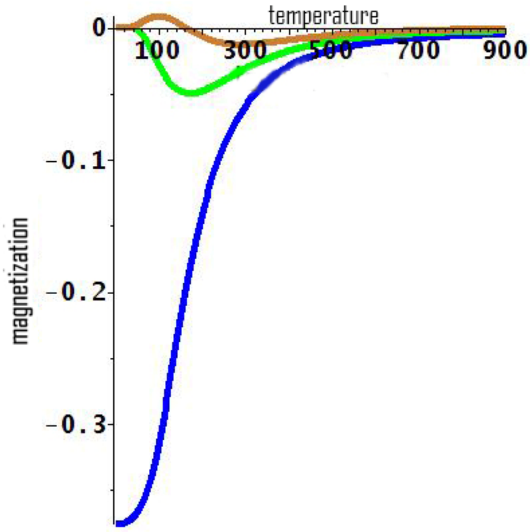


Figure 5. Non-homogeneity : 0.0 (blue line), 0.6 (green line), 0.9 (gold line), Here: N=8, the number of configuration 1210

5. CONCLUSION

Amorphous alloys based on iron are widely used in modern electronics. Knowing microstructure of those alloys plays a key role, because of ferromagnetic properties, good mechanical properties and high corrosion resistance. Their use is important in devices such as transformers, sensors, microelectronic equipment, even dental and medical implants. The stability of amorphous alloys is their important feature, and it is directly related to the process of crystallization in the alloy. The thermic treatment of these systems causes the transformation of amorphous non-arranged in a arranged crystal state. In our computer experiments we perform a large number of combinations with non-homogeneity, and as it is presented above, the results are compatible with experiments performed by other scientists.

Figure 2 presents the results of experiments, showing that with increasing non-homogeneity, critical temperature of phase transition is growing as well. This result corresponds to the experiments conducted by Zaikov et al. [10].

In Figure 3 it can be seen that, with an increase of the number of configurations, there is a corresponding increase of magnetization. When N is large, it would take a huge number of configurations to provide a good amount of magnetization. By moving to a larger number of configurations, the shift of critical temperature will not disappear. The distance will become higher.

In Figure 4, a very interesting result is presented: increasing non-homogeneity results in a decreasing critical phase transition temperature [10].

Figure 5 presents the result of how amorphization can destroy the magnetization.

This is a new, very simplified model with interesting, significant results. It is very important to note that our very simplified model corresponds well with the experimental results of other authors [10].

J. Li, et al investigated magnetic properties and magnetocaloric effect in Fe–Tm–B–Nb metallic glasses [11]. They found that the appropriate substitution of Fe by Tm increases the glass-forming ability of the alloys and allows tuning the Curie temperature (T_C) to near room temperature.

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УТИЦАЈ АМОРФИЗАЦИЈЕ НА КРИТИЧНУ ТЕМПЕРАТУРУ ФЕРОМАГНЕТА

Сажетак: У физици чврстог стања у новије вријеме велико интересовање је привукао проблем феромагнетизма и магнетизма уопште, у структурно аморфним материјалима, како у теоријским, тако и у експерименталним истраживањима. Познато је да кристална и аморфна структура исте супстанце немају исте особине. Аморфни магнети чине класу система са највишим степеном неуређености. Постојање феромагнетизма у аморфизованим материјалима одређено је релацијом између интеракције размјене и конфигурације магнетних атома. У компјутерским експери-

ментима представљеним у овом раду, кориштен је софтвер опште намјене Maple, те упрошћен Изингов модел, који подразумијева да се ради о феромагнетику са нешто антиферомагнетног стања. Проучаван је утицај аморфизације материјала на критичну температуру феромагнета. Посматрана је промјена спонтане магнетизације у зависности од температуре, у температурном опсегу блиском критичној температури, те помак критичне температуре за различите утицаје нехомогености енергије интеракције. Добијени резултати упоређени су са резултатима других аутора који се баве истом тематиком.

Кључне ријечи: феромагнетизам, критична температура, аморфизација.