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THE STUDY OF THE INFLUENCE OF GAMMA RADIATION ON DIELECTRIC PROPERTIES OF $TlGaSe_2$ CRYSTALS

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Abstract: The dielectric parameters of the layered structured $TlGaSe_2$ crystals have been studied comparatively before and after gamma radiation (20Mrad). The dielectric parameters - the real and imaginary parts of dielectric permittivity and dielectric loss angle have been studied in the paraelectric phase in the temperature range of 300-500K. The role of free ions in the relaxation process has been determined when it is f <10kHz on the basis of the dielectric parameters in the frequency range of 100-10^6Hz. The non-standard mutual dependence of the real and imaginary parts of the dielectric permittivity has been observed.

Keywords: dielectric permittivity, dielectric loss, ionic conductivity, real and imaginary part

1. Introduction

The materials with high ionic conductivity have recently been in the focus of researchers all over the world [1,10]. So, these materials are now used as a small-sized energy current source in different sensors and solar cells [2]. One of the perspectives of the application of these materials is to use it in devices that convert thermal energy which is relevant to chemical bond into electrical energy. However, there are many problems in terms of solving these issues. It is required to obtain stable materials with high ionic conductivity in order to solve these problems. As a result of progress, modern microelectronics needs creation of new semiconducting materials with both electron and ionic conductivity [3]. However, despite the fact that a large number of complex-structured chalcogenide compounds have relatively low-temperature ionic conductivity, these properties have not been studied or studied very little. Also, until nowadays the materials with both electron and ionic conductivity that are essential for material science have not been researched in the wide ranges of temperature [4]. In the last decade, there has been a great interest in researching chained $A^3B^3C_2^6$ group semiconductor compounds [5,6,8,9]. Despite the practical application potentials of these crystals, these opportunities have not been realized because of the lack of detailed information about their physical properties.

The formation and study of new super ionic compounds are essential for modern microelectronics. From this point of view, the study of both electron and ionic conductivity of complex-structured chalcogenides is topical. As it is known, superionic compounds belong to non-regular materials. It is also known that radiation defects increase the irregularity of the materials. Therefore, the study of the effects of ionizing rays on ionic conductivity of substances is of great importance for radiation material science. For this reason, the effect of electric load transfer mechanism and gamma radiation on relaxation processes has been investigated in $TlGaSe_2$ crystals included in the $A^3B^3C_2^6$ group in the this research [11].

2. Practice

The synthesis of $TlGaSe_2$ compounds was performed by mixing the initial components according to stoichiometric ratio, and the monocrystals were grown by Bricmen Stokbarger method. Geometrical parameters of the samples (in a parallelepiped form) used in experiments are as 5x2x2 mm^3. Silver electrodes were used as electrical contacts in the study of dielectric properties. All measurements were made in the direction that is perpendicular to the "c" axis of crystal. Complex dielectric measurements were carried out on the MNIPI E7-25 impedance analyzer device. The experiments were conducted in the frequency range of $100\text{-}10^6$Hz and temperature range of 120-450K. The samples are heated by 0.1K/min and controlled by thermocouple in the experiments.

3. Conclusion and Discussion

The temperature and frequency dependencies of the dielectric properties of $TlGaSe_2$ samples were studied for different frequency and temperature constants accordingly in the researches. The experiments were carried out in the frequency range of 100Hz - 1MHz according to various temperature and frequency constant. The measurements reveal that the temperature and frequency dependence of the real and imaginary parts of the dielectric permittivity are different at various frequency and temperature. Figure 1 depicts the temperature dependences of the real and imaginary parts of the dielectric permitivity before and after gamma radiation. As can be seen from the figure, some changes are observed in the real and imaginary parts of the dielectric permittivity as a result of gamma radiation. Some deviations are detected at the temperature of 370 K in the real part of the dielectric permittivity before radiation. The available peaks slide to the temperature of 315K as a result of the effect of gamma radiation. Unlike the real part of the dielectric permittivity, no peak is observed in the imaginary part before gamma radiation. However, analogical state of the real part occurs in the imaginary part of the dielectric permittivity after gamma radiation. Thus, the maximum is detected at the temperature of about 317 K in the imaginary part of the dielectric permittivity. In all cases, the numerical value of the real and imaginary parts of the dielectric permittivity increases according to the rise in temperature after the effect of gamma radiation in the range of T> 340K. The numerical value of the real part of the dielectric permittivity increases by the effect of gamma radiation. The imaginary part of the dielectric permittivity is exposed to a numerical value decrease by the effect of gamma radiation. The temperature dependence of the real part of the dielectric permittivity weakens in relatively high values of frequency (f> 1kHz) and remains almost constant. When 20Mrad dose of gamma rays is applied to the samples , new properties occur in the value and temperature dependence of the real part of the dielectric permittivity. The constancy in the real and imaginary parts of the dielectric permittivity in non-irradiated $TlGaSe_2$ crystals in relatively low values of temperature (300-400K) shows the connection with certain mechanism of the relaxation process - dipole relaxation of polar molecules (Figure 1). A significant increase is observed for the values of both eps1 and eps 2 by the temperature rise in relatively high values of the temperature (T> 400K). This is the highest increase in the low values of frequencies, and the increase rate decreases by the rise in frequency. When it is f> 10kHz, the increase is almost impossible to be observed. This dependence is mainly related to ion-conducting materials and is based on the rise in ionic mobility by temperature increase. $TlGaSe_2$ crystals are known to have ionic conductivity along with electron conductivity in carrying electrical charges [7]. The inertia of ions leads to the weakening in polarization process by the increase in frequency. Although the high-temperature region is maintained in crystals which are excited by gamma rays, the change in eps1 and eps2 can be associated with radiation defects that occured in the low-temperature region around 300-320K. As the ionic conductivity is not large now in this region, the dielectric permittivity decreases by the increase in temperature. So, the temperature has the opposite effect on the relaxation process. The change in the numerical values of both the real and the imaginary parts of the dielectric permittivity during the radiation can be directly correlated with the effect of radiation on relaxation processes. The curves of temperature dependences of dielectric losses can also be interpreted anologically (Figure 2). However, the dependence of the loss angle on the temperature weakens in irradiated crystals even at low frequencies. Perhaps, there occurs obstacles in the arrangement of the active ions as a result of gamma radiation.

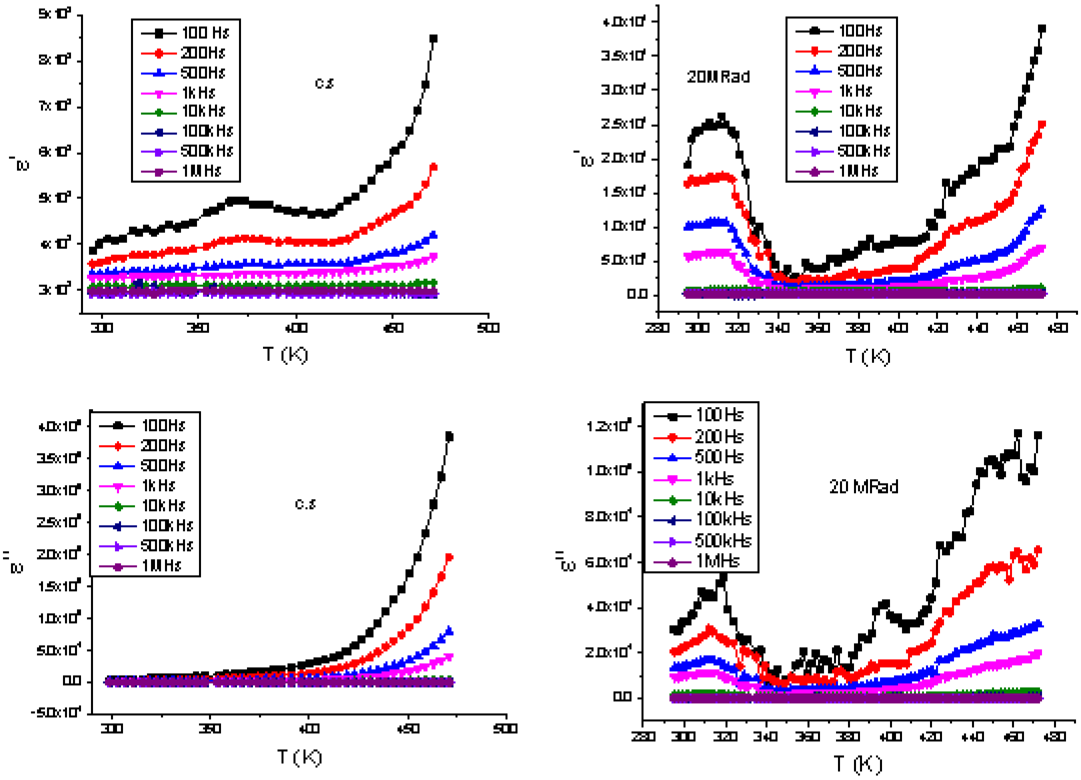

Fig. 1. The temperature dependencies of the real and imaginary parts of the dielectric permittivity before and after gamma radiation

The temperature dependencies of the dielectric losses before and after gamma radiation are described in Figure 2. The sharp contrast was observed in the temperature dependence of the dielectric losses after gamma radiation. The deviations were detected at temperatures about 337 K and 445 K. Dielectric losses reduced about five times after gamma radiation. On the other hand, chaotic state occured in the temperature dependence of the dielectric losses after gamma radiation.

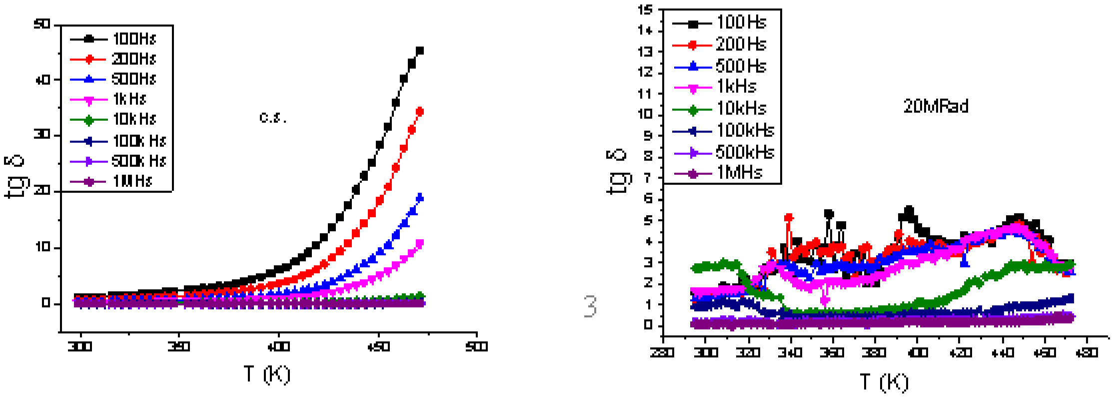

Fig. 2. The temperature dependencies of the dielectric losses before and after gamma radiation

To illustrate the effect of radiation more clearly, the frequency dependence of the dielectric parameters was described at fixed temperatures (figure 3,4).

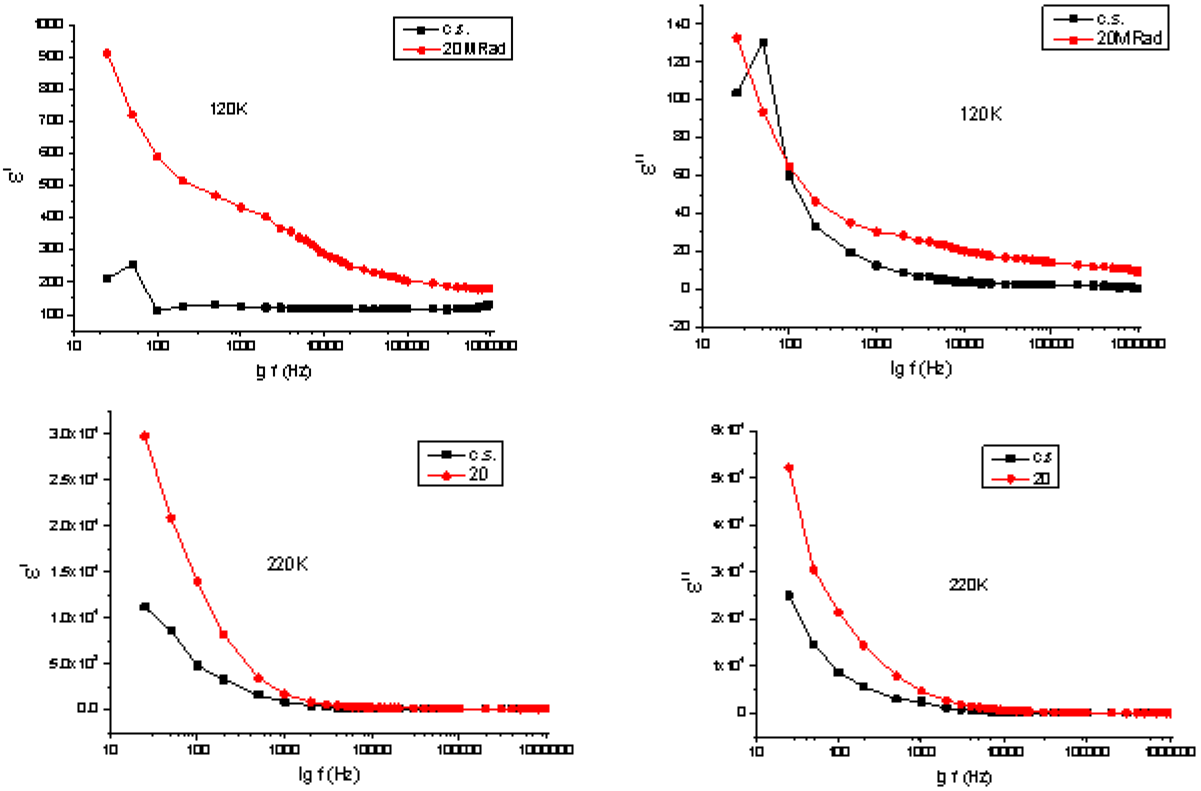

Fig. 3. The frequency dependences of the real and imaginary parts of the dielectric permittivity before and after gamma radiation at the temperatures of 120K and 220K

According to these dependencies, the significant changes at low frequencies in the real and imaginary part of the dielectric permittivity show the relaxation mechanism and here, the role of the ions as a result of radiation. The frequency dependences of the real and imaginary parts of the dielectric permittivity were described at fixed temperatures of 120K and 220K before and after gamma radiation in figure 3. As can be seen from the figure, there is a tendency of decrease in the dielectric permittivity by the increase in the frequency at both temperatures. At the same time, the increase in the numerical value of the dielectric permittivity by the effect of gamma radiation is evidently seen in the figure. The stabilization is seen at the temperature of 220K in the frequency region of f> 3kHs for the real part and f> 3.5kHz for the imaginary part of the dielectric permittivity although this has not been observed at the temperature of 120K. The numerical value of the dielectric permittivity remains constant in the high values of the frequency (10^3-10^6Hz) and does not depend on the frequency.

The frequency dependences of the real and imaginary parts of the dielectric permittivity were depicted in figure 4 at the temperature of 290K and 430K before and after gamma radiation. Unlike low temperatures, the real part of the dielectric permittivity increases after radiation, while the imaginary part decreases. At these temperatures, the real and imaginary parts of the dielectric permittivity remain constant in the high values of the frequency (f>10^3Hz), but rapid decrease is observed by the increase in the frequency in the low values of the frequency.

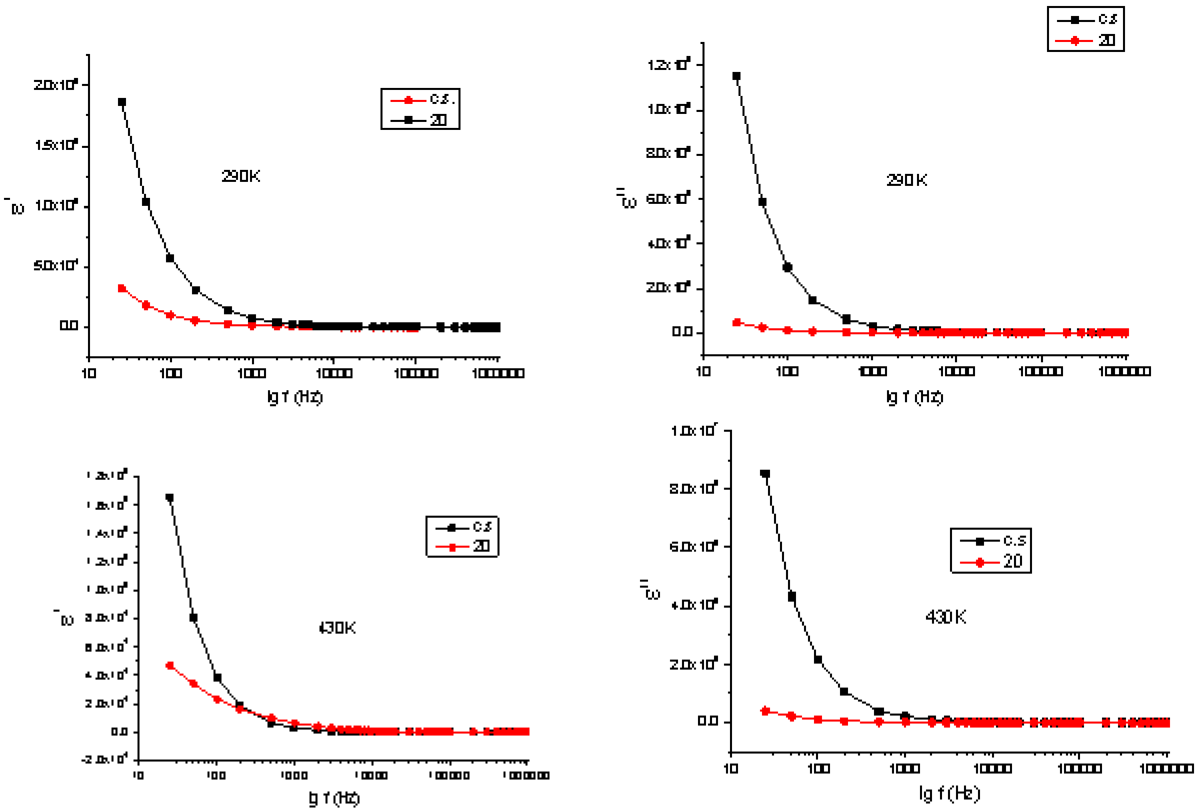

Fig. 4. The frequency dependences of the real and imaginary parts of the dielectric permittivity before and after gamma radiation at 290K and 430K temperatures

Figure 5 shows the frequency dependences of the dielectric losses before and after gamma radiation.

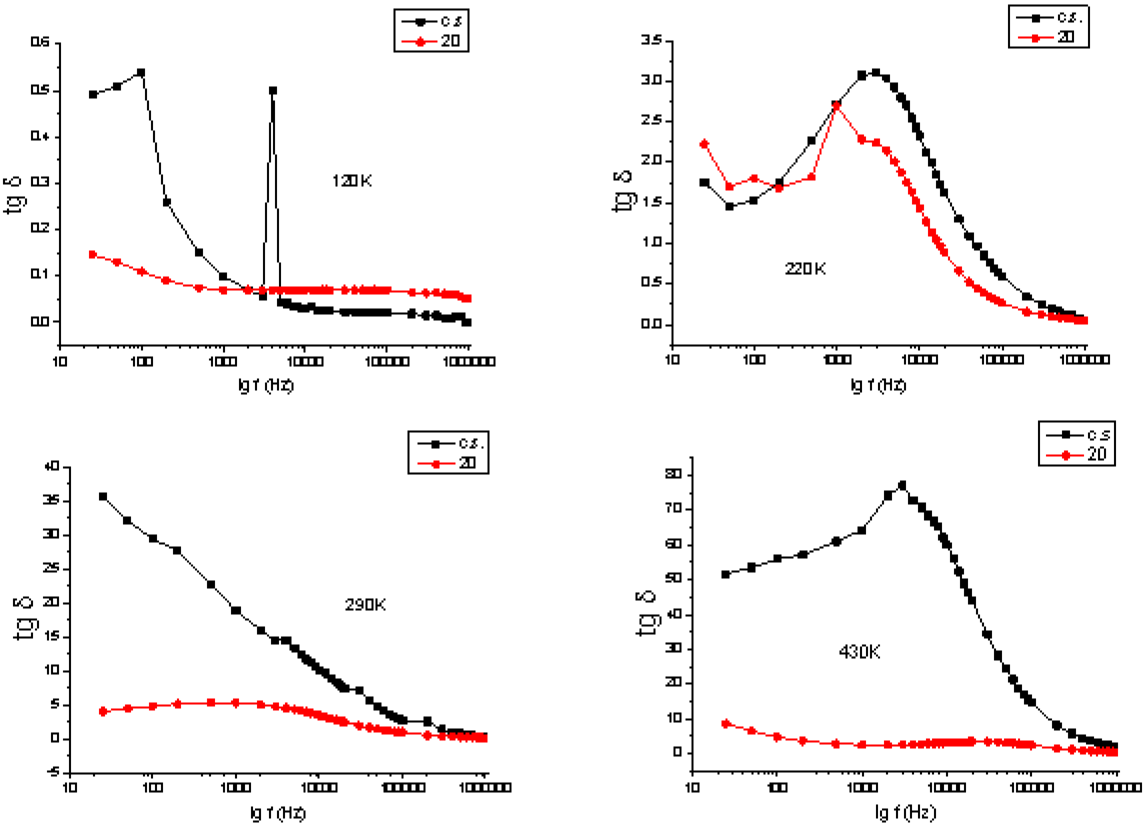

Fig. 5. The frequency dependencies of the dielectric losses before and after gamma radiation

As it is seen in the figure, the dielectric losses reduce by the effect of gamma radiation. The maximum has been observed at the temperature of 220K and frequency of 2.7kHz, which corresponds to the value of 3.7×10^{-4}sec of the relaxation period. In contrast to the dielectric permittivity, the change in dielectric losses occurs in the entire frequency range according to numerical values.

The mutual dependencies of the real and imaginary parts of the dielectric permittivity before and after gamma radiation are described in Figure 6. As can be seen from the figure, the cases similar to Cole-Cole curves are observed almost at all temperatures.

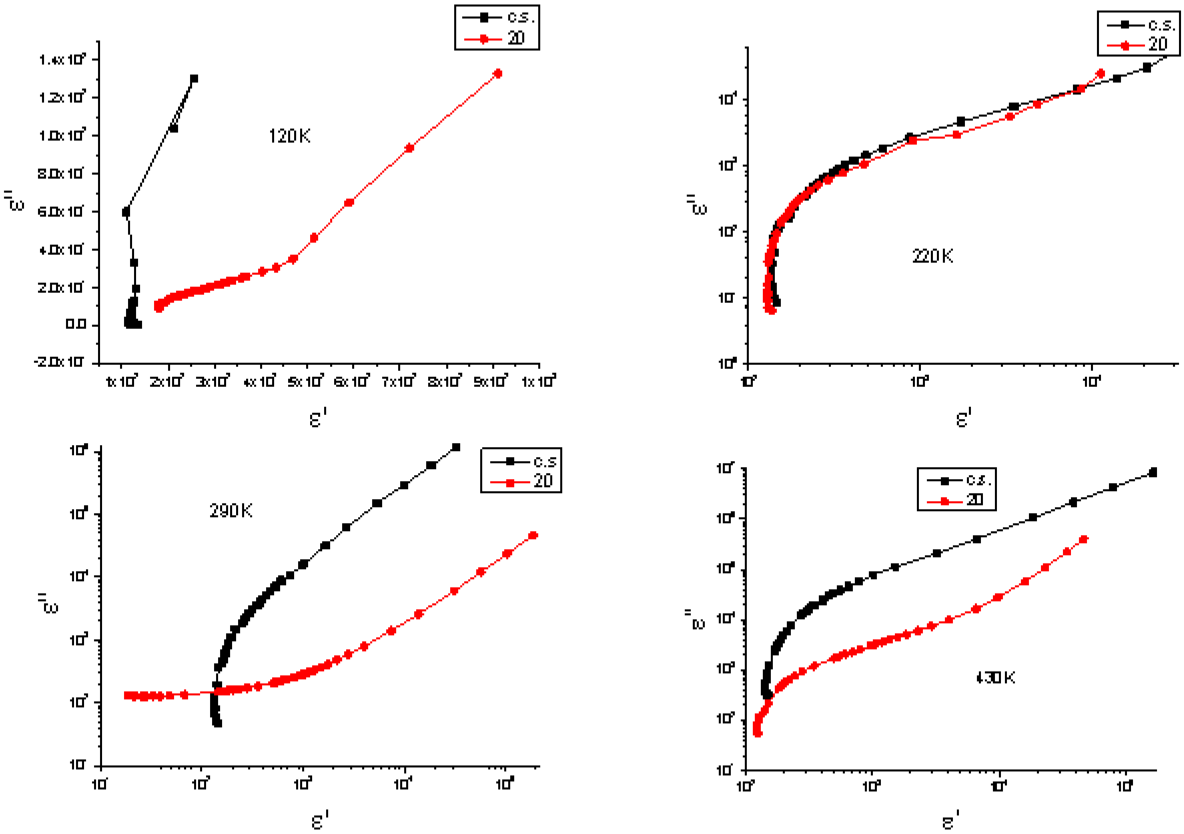

Fig. 6. The mutual dependences of the real and imaginary parts of the dielectric permittivity before and after gamma radiation

While the higher frequencies are in conformity with the standard shape, this is not a case at low frequencies in the relation between the real and imaginary parts of the dielectric permittivity. This may be an indication of the coexistence of several relaxation processes. The calculated value of the relaxation period is 10^{-4}sec order for $TlGaSe_2$ crystal according to the value which is compatible with the maximum in the extrapolation of distorted Cole-Cole diagram.

4. Results

Constant and strongly changed temperature regions of the dielectric permittivity have been determined based on the frequency and temperature dependence of the dielectric parameters. The strong increase of eps1 and eps 2 depending on the temperature is the result of Tl ions mobility and their activation by temperature in $TlGaSe_2$ crystals. The changes in dielectric properties by the effects of 20Mrad irradiation provide a change in ionic mobility by the formation of radiation defects. The high value of the dielectric permittivity in the paraelectric phase and its high level during radiation allow the use of these materials in ionizing environments.

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ИЗУЧЕНИЕ ВЛИЯНИЯ ГАММА-ИЗЛУЧЕНИЯ НА ДИЭЛЕКТРИЧЕСКИЕ СВОЙСТВА КРИСТАЛЛОВ $TlGaSe_2$

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Резюме: Исследованы диэлектрические параметры слоистых структурированных кристаллов $TlGaSe_2$ до и после гамма-излучения (20Mrad). Исследованы диэлектрические параметры- действительная и мнимая часть диэлектрической проницаемости и угла диэлектрических потерь в параэлектрической фазе в интервале температур 300-500к. Определена роль свободных ионов в релаксационном процессе при f <10кГц на основе диэлектрических параметров в диапазоне частот 100-106гц. Наблюдалась нестандартная взаимная зависимость действительной и мнимой частей диэлектрической проницаемости.

Ключевые слова: диэлектрическая проницаемость, диэлектрические потери, ионная проводимость, действительная и мнимая часть

QAMMA ŞÜALANMANIN $TlGaSe_2$ KRİSTALLARININ DİELEKTRİK XASSƏLƏRİNƏ TƏSİRİNİN TƏDQİQİ

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Xülasə: Laylı quruluşa malik $TlGaSe_2$ krsitallarının dielektrik parametrləri gamma şüalanmadan öncə və sonra (20Mrad) müqaisəli öyrənilmişdir. 300-500K temperatur intervalında paraelektrik fazada dielektrik parametrləri – dielektrik nüfuzluğunun həqiqi və xəyali hissələri, dielektrik itki bucağı tədqiq olunub. Dielektrik parametrlərinin 100-106Hz tezlik intervalında tədqiqi əsasında, f<10kHz olduqda relaksasiya prosesində sərbəst ionların rolu müəyyənləşdirilmişdir. Dielektrik nüfuzluğunun həqiq və xəyali hissələrinin qarşılıqlı asılılıqlarının standartdan kənara çıxması müşahidə olunmuşdur.

Açar sözlər: dielektrik nüfuzluluq, dielektrik itki, ion keçiriciliyi, həqiqi və xəyali hissə