ISSN 1027-5495. Functional Materials, 23, No.3 (2016), p. 378-381.
doi:http://dx.doi.org/10.15407/fm23.03.378

Inhomogeneity of dielectric properties of cadmium zinc-telluride crystals grown from melt

***O.O.Poluboiarov*[1], *O.N.Chugai*[2], *O.O.Voloshin*[2], *D.P.Zherebyatiev*[2], *S.V.Oleynick*[2], *S.V.Sulima*[1]**

[1]Institute for Single Crystals, STC "Institute for Single Crystals", National Academy of Sciences of Ukraine, 60 Nauky., 61001 Kharkiv, Ukraine
[2]N.Zhukovsky Kharkiv National Aerospace University, 17 Chkalova Str., 61070 Kharkiv, Ukraine

Received February 16, 2016

Dielectric properties of $Cd_{1-x}Zn_xTe$ crystals made from different ingot regions were investigated in a low-frequency region. Wavelet analysis was used for take-off of regular component in dependence of both parts of dielectric permittivity from spatial coordinate. It is ascertained that dielectric response of crystals has a relaxational character. Regular changes of response characteristics in ingot growth direction were revealed. Such peculiarities of properties are explained with changes during growth process not only in ratio of solid solution basic components, but also of intrinsic structure defects, especially related with cadmium vacancies.

Keywords: semiconductors solid solutions, CdZnTe crystal, native defects, dielectric permittivity.

В низкочастотной области исследованы диэлектрические свойства кристаллов $Cd_{1-x}Zn_xTe$, изготовленных из разных частей слитка. Для выделения закономерной составляющей зависимости от пространственной координаты обеих частей диэлектрической проницаемости применяли вейвлет-анализ. Установлено, что диэлектрический отклик кристаллов носит релаксационный характер. Обнаружены закономерные изменения характеристик отклика в направлении роста слитка. Эти особенности свойств объяснены изменением в процессе роста не только соотношения основных компонентов твердого раствора, но и собственных дефектов структуры, особенно связанных с вакансиями кадмия.

Неоднорідність діелектричних властивостей кристалів телуриду кадмію-цинка, вирощених з розплаву. *О.О.Полубояров, О.Н.Чугай, О.О.Волошин, Д.П.Жеребятьєв, С.В.Олійник, С.В.Сулима.*

У низькочастотній області досліджено діелектричні властивості кристалів $Cd_{1-x}Zn_xTe$, виготовлених із різних частин злитку. Для виділення закономірної складової залежності від просторової координати обох частин діелектричної проникності застосовували вейвлет-аналіз. Встановлено, що діелектричний відгук кристалів має релаксаційний характер. Виявлено закономірні зміни характеристик відгуку у напрямку росту кристала. Ці особливості властивостей пояснено зміною у процесі росту не тільки співвідношення основних компонентів твердого розчину, але й власних дефектів структури, особливо пов'язаних з вакансіями кадмію.

1. Introduction

A well proven fact is that composition inhomogeneity is a characteristic feature of solid solution semiconductors. Growth conditions have significant influence on this peculiarity of crystal composition. Thus, in $Cd_{1-x}Zn_xTe$ (CZT) crystals as micro-, as macroinhomogeneities in composition appear during growth from melt. It is important that in certain cases the first ones contain regular (periodical) component in the crystal ingot growth direction [1], and the second ones in the direction perpendicular to specified [2]. These components of composition inhomogeneity appreciably affect electrical properties of the CZT crystals in low-frequency region. It matters considering wide use of given crystals in uncooled gamma-ray detectors, as far as technical characteristics of these devices depend from mentioned properties of the crystal semiconductor [3].

Regular changes of composition in the growth direction always emerge in the CZT crystals during growth from melt. They are specified by changes in the melt composition [4], difference in segregation coefficients of background dopants [5] and other causes. Taking into account the given above, it is interesting to study the regular change of low-frequency dielectrical properties of the CZT crystals in specified direction. Implementation of such investigation is the purpose of this work.

2. Experimental

We investigated $Cd_{1-x}Zn_xTe$ ($x = 0.05$–0.15) crystals grown from melt under high pressure of inert gas. Charge preparation and growth conditions are given in [6]. Crystals' composition was estimated by energy dispersive method using electron microscope REM-106. Specimens were made by cutting a right-angled wafer from central part of the crystal ingot ($\varnothing = 60$ mm). Wafer surface was oriented parallel to growth direction Z. The wafer was cut to cuboid form specimens $8{\times}8{\times}6$ mm^3. The cutting was performed in order to their planes were parallel or perpendicular to direction Z. After cutting all facets of the specimens were sequentially mechanically grinded, polished and chemically etched. The etching ensured removal of affected subsurface layer. Electrical contacts to greater planes oriented parallel to direction Z were created by coating with conducting lacquer TLC. Real ε' and imaginary ε'' parts of ε^* were measured in the low-frequency region with condenser-type method using immittance meter LCR-819 by Instek (Taiwan) with an original measuring cell. The specimen partially fills space between electrodes in the cell. The amplitude of voltage on the specimen was 1 V.

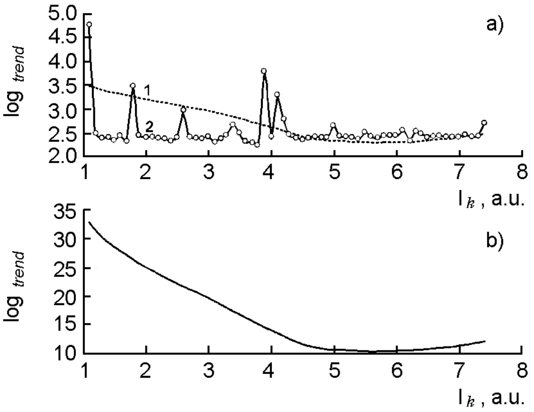

Fig. 1. Dependences of dielectric permittivity real part and its regular component from spatial coordinate (a), b — the same dependence for regular component in linear scale.

Experimental dependences for ε' and ε'' from the spatial coordinate, of course, contain not only regular, but also random components. We used wavelet analysis for extraction of the first one from the experimental data as it described in our works [1, 2]. At this the two-dimensional array of these values i.e. $\varepsilon'(r_j, Z_j)$ and $\varepsilon''(r_j, Z_j)$ (where r_j is a coordinate in radial direction, and Z_j — in the axial one), was transformed in the one-dimensional $\varepsilon'(l_k)$, $\varepsilon''(l_k)$, continuing the series with fixed values Z_j with the next series (in increasing order of j).

3. Results and discussion

Experimental dependence of the real part of ε^* from the spatial coordinate i.e. $\varepsilon'(l_k)$ is shown in Fig. 1a. This dependence has been obtained with transformation from the two-dimensional array to the one-dimensional one as described above. We should notice that this dependence contains peaks which are corresponding to the regions near borders of the crystal ingot. Dependency of the regular part of the same value $\varepsilon'_{tr}(l_k)$ (trend) is given in the same picture. It is obtained as a result of the experimental data wavelet filtration. Fig. 2 shows two-dimensional distribution of ε'_{tr} with the lines indicating similar investigated values. We should specify that the analogous experimental and filtered data dependences for

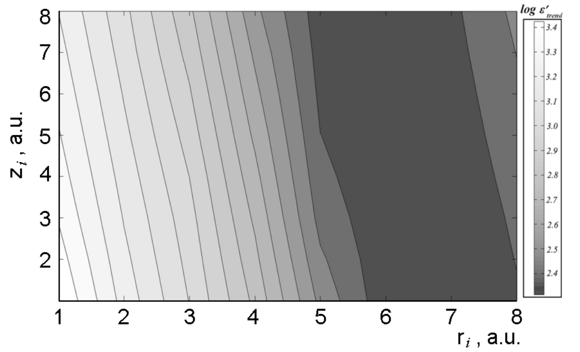

Fig. 2. Two-dimensional distribution for regular component of dielectric permittivity real part in $Cd_{1-x}Zn_xTe$ ingot.

imaginary part of ε^* are qualitatively similar to given.

Typical temperature dependences of ε' and ε'' for the specimens from initial and terminal parts of the crystal ingot are shown in Fig. 3. As we can see, both this values significantly depend from temperature T. Presence of the maximum in dependence $\varepsilon''(T)$ is characteristic for the specimens from the ingot terminal part. Temperature T_{max} which corresponds to this maximum increases for the specimens lying more distant from the ingot beginning (Fig. 4).

Existence of the mentioned above regular part of ε' in $Cd_{1-x}Zn_xTe$ ingot growth direction seems natural, because change in chemical and defect-impurity composition of the ingot corresponds to transition in this direction. At that Zn segregation and cadmium vacancies V_{Cd} formation in form of separate defects or components of associates play the key role [7]. Apparently, drastic increase of ε^* components near the ingot edges is connected with V_{Cd}. The nature of this anomaly (essentially non-uniformity) of investigated crystals dielectric properties, in our opinion, could be the subject of a separate study.

Turning to the regular change of ε'_{tr} within the investigated part of the ingot, it is important to note that the segregation coefficient of Zn is greater than one [8]. Therefore layers of $Cd_{1-x}Zn_xTe$ solid solution deplete more and more with this component during growth from the melt. Assuming the determining influence of composition on dielectric properties of investigated crystals it should be expected the increase of ε'_{tr} at displacement to the terminal part of the ingot, as its value in ZnTe is less than in CdTe (10.1 [9] and 11.0 [10], respectively). However, the character of ε' change in major part of the investigated ingot doesn't match this assumption (see Fig. 1). The main reason for this discrepancy, in our view, is the significant influence of intrinsic crystal defects including V_{Cd} and residual impurities on polarization process. This influence will be discussed further.

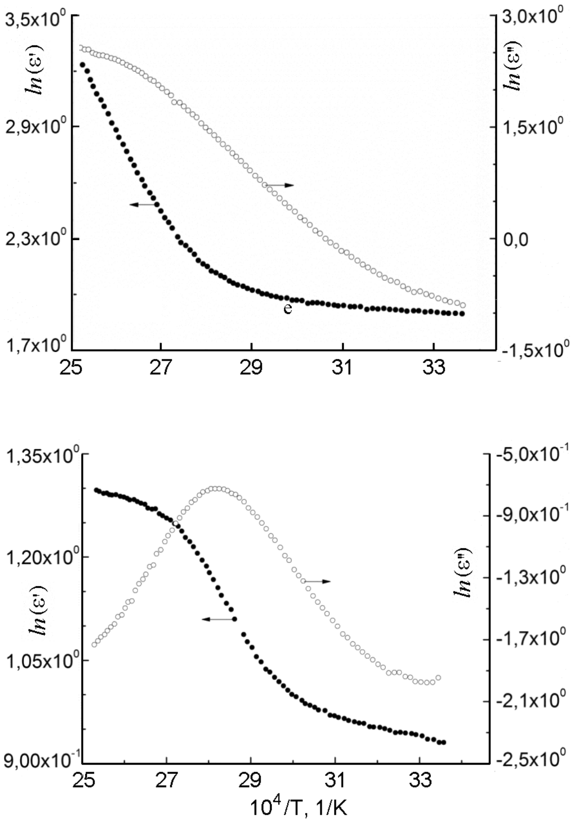

Fig. 3. Temperature dependences for real and imaginary parts of dielectric permittivity typical for specimens from initial (a) and terminal (b) parts of crystal ingot.

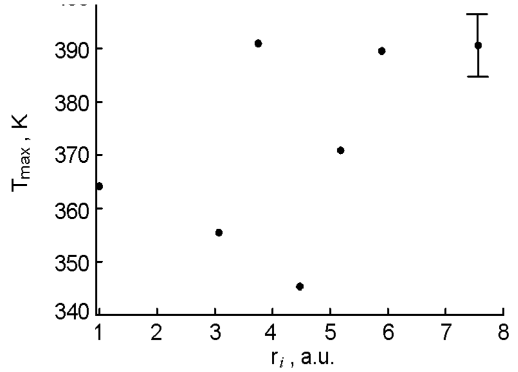

Fig. 4. Position of maximum of temperature dependence for imaginary part of dielectric permittivity depending on distance from beginning of crystal ingot.

Interesting feature of ε'_{tr} regular component behavior within the investigated region (see Fig. 2) is slope of the current value isolines by angle different from $\pi/2$ relatively to the ingot axis (Z axis). Such slope of ε'_{tr} isolines, in our opinion, is determined by orientation of crystallization front in relation to the direction of gravity and therefore growth (Z axis). In fact, the shape of the front determines not only the shape of the constant composition surface [11] in $Cd_{1-x}Zn_xTe$ crystals, but also the shape of the impurity bands [12] in the crystals grown from the melt. The main cause of crystallization front tilt against melt surface is disturbance of the thermal field symmetry in the crystallization region [12].

It is well-known that crystal growth from melt occurs in varying thermal conditions. Due to change of the thermal conditions and segregation coefficient not only of Zn, but for majority of residual impurities difference from one [5] composition of the growing crystal also changes. As a result the change in concentration of inhomogeneously distributed intrinsic defects which have the determinative influence on the crystals dielectric properties is observed. This assumption is confirmed by difference in types of the temperature dependences of ε' and especially ε'' for regions from initial and terminal parts of the crystal ingot (see Fig. 3). The attention should be paid on that fact that $\varepsilon''(T)$ dependence maximum is observed at the same temperature at which the absolute value $\partial\varepsilon'/\partial T$ reaches the maximum. Tendency of T_{max} increasing for the specimens lying more distant from the ingot beginning is observed (Fig. 4). We reported about observing of the $\varepsilon''(T)$ dependence maximum in CZT crystals within the region of the most rapid increase of ε' with temperature in work [13]. This peculiarity of the dielectric properties is explained with presence of potential relief appearing in semi-insulating crystal due to the inhomogeneous distribution of charged point defects (impurities). Moreover in the case when during electric field half-period charge carriers overcome only one potential barrier with height U, for angular field frequency ω and T_{max} the following relation is true [14]:

$$\omega^{-1} = \tau_0 \exp\left(\frac{U}{kT_{\max}}\right),$$

where τ_0 is relaxation time, k is the Boltzmann constant. It is quite possible that the potential relief for the reasons specified above has its peculiarities in different parts of the ingot. This is reflected in the change of maximum position of $\varepsilon''(T)$ dependence with transition to the specimen from another part of the ingot.

4. Conclusions

Significant inhomogeneity of dielectric properties is characteristic for $Cd_{1-x}Zn_xTe$ crystals grown from melt. Wavelet-analysis of changes in parts of complex dielectric permittivity within major region of the crystal ingot allowed to take-off the regular component of this changes. For investigated region the difference between maximum and minimum values reached 3 times. It is ascertained that electric polarization of the crystals has relaxational character. Not only composition but also intrinsic defects inhomogeneously distributed within the ingot volume appreciably affect the polarization.

Publication includes results of the research provided by grant support of the State Fond for Fundamental Research within the framework of the competitive project F64/5862.

References

1. O.N.Chugai, S.L.Abashin, A.V.Gaidachuk et al., *Visnyk KhNU im.Karazina, seriya "Fizika"*, **1158**, 13 (2015).
2. O.N.Chugai, S.L.Abashin, A.V.Gaidachuk et al., *Inorg.Mat.*, **51**, 972 (2015).
3. C.Szeles, *Phys.Stat.Sol.(b)*, **241**, 783 (2004).
4. J.E.Toney, B.A.Brunett, T.E.Schlesinger et al., *Nucl.Instr.Meth.Phys.Res.A*, **380**, 132 (1996).
5. T.E.Schlesinger, J.E.Toney, H.Yoon et al., *Mater.Sci. Eng.R*, **32**, 103 (2001).
6. Yu.V.Shaldin, I.Warchulska, M.Kh.Rabadanov, V.K.Komar', *Semiconductors*, **38**, 288 (2004).
7. M.Fiederle, A.Fauler, J.Konrath et al., *IEEE Trans.Nucl.Sci.*, **5**, 1864 (2003).
8. G.Li, X.Zhang, H.Hua, W.Jie., *J.Electron. Mater.*, **34**, 1215 (2005).
9. D.Berlincourt, H.Jaffe, and L.R.Shiozawa, *Phys.Rev.*, **129**, 1009 (1963).
10. I.Strzalkowski, S.Joshi, C.R.Crowell, *App. Phys.Let.*, **28**, 350 (1976).
11. M.Azoulay, S.Rotter,G.Gafni, M.Roth, *J. Cryst.Growth*, **116**, 515 (1992).
12. Yu.M.Tairov, V.F.Tsvetkov, Tehnologiya Poluprovodnikovyh i Dielektricheskih Materialov, Vysshaya Skola, Moscow (1983) [in Russian].
13. V.K.Komar', V.P.Migal', D.P.Nalivaiko, O.N.Chugai, *Inorg.Mat.*, **37**, 449 (2001).
14. Yu.M.Poplavko, Fizika dielektrikov. Vyshca Skola, Kyiv 1980) [in Russian].