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Morphological Features of Gallium Arsenide Crystals Grown at Low-frequency Influences to the Crystallization Front

V.G. Kosushkin[1], S.L. Kozhitov[2], L.V. Kozhitov[2], Yu.N. Parkhomenko[2], L.M. Chervjakov[3]

[1] *Bauman Moscow State Technical University (Branch in Kaluga), 2, Bazhenov Str., 248000 Kaluga, Russia*
[2] *National University of Science and Technology MISIS, 4, Leninskii Pr., 119049 Moscow, Russia*
[3] *Southwest State University, 94, 50 let Oktyabrya, 305040 Kursk, Russia*

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It was found experimentally that on the initial part of crystal the fluctuations with amplitude more than 1 mm leads to break of the capillary column melt and close of growth. The physical significance of this functional relationship for this probably lies in the different orientation of surface tension forces. Regardless of the direction of stretching and an amplitude -frequency characteristics of development process of the power of the octahedral facets increased with increasing growth rate. Accidents on existing ideas are the result of periodic growth, due, for example, the rotation of the crystal in an asymmetric thermal field. When carrying out the method of crystal growth with perturbations at the interface it to a solid phase, the lateral surface is also composed of corrugations distinguishable to the naked eye.In general, the study of structural defects in the crystals obtained in exacting heat conditions, showed that in this case, low-frequency disturbance of the melt at the interface reduces the average density of dislocations due to the periodic melting of crystallization and partially "heal" the defective portions of the crystals.

Keywords: Low-frequency influences, Homogeneity.

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1. INTRODUCTION

One way to improve the uniformity of single crystals grown by the Czochralski method is the use of artificial vibrations introduced into a melt in various ways. The goal of this work was to determine the possibility of increasing the homogeneity of gallium arsenide single crystals. A standard "Astra"design used for the experiments.The technology is described in [1-7]. Seeding was performed by the Dash method, i.e. formed under the seed single crystal with a diameter less than the seed, after which it increased to the proper diameter at a certain angle.

2. EXPERIMENTAL AND RESULTS

It was found experimentally that at the beginning of the process including fluctuations controlled led to the breakdown of the single-crystal growth. On the initial part of crystal, when the diameter was less than 3 mm, the fluctuations with amplitude more than 1 mm leads to break of the capillary column melt and close of growth. The failure of the melt column beneath the chip held by capillary forces did not occur during vibration with amplitude of up to 2 mm and frequencies up to 20 min^{-1}. At high frequencies of melt promised by capillary forces, and the growth of single crystal burst was stop. Different resistance at the same column, depending on the diameter of the crystal expands or contracts. It determines the fact that the equilibrium is a function of elevation angle of the melt to meet with the crystal. The physical significance of this functional relationship for this probably lies in the different orientation of surface tension forces. When vibrations of the melt due to accelerations, in addition to this there are gravity and inertial forces which reduce the height of the column so critical that any diameter of the crystals to grow at a sweep oscillation 3 mm could not be in a frequency range of 3-100 min^{-1}.The equilibrium height of the crystal for gallium arsenide diameter greater than 50 mm is almost insensitive to changes and it is 4-6 mm. It is twice the maximum acceptable under the conditions of our experiments, the oscillation amplitude. In the frequency range of 3-80 min^{-1} and range 0.5-2.4 mm oscillations at all speeds used in the 8-10 mm/h, stable, with good geometry grew crystals up to 100 mm from the crucible diameter of 200 mm, increased to 15-20 degrees per centimeter of temperature gradients in the melt area under the crystal. Orientation experiments clarify the relationship uniformity crystals with parameters of low-energy impacts, determined the choice of the following tactics conducting the experiments: grown quite long (up to 130 mm) crystals in the formation of which alters the oscillation frequency. Thus crystal represented himself as a few samples, typically 20-25 mm in height, obtained in the same process with different parameters and divided by its control regions corresponding standard conditions of the process.

During crystal growth in the [110] directiontheir apparent symmetry group responsible 2m. This symmetry is determined mainly by {111} faces, four of which are parallel to the growth direction, while the other two were with this direction angle of 35°16′. In the future, these two varieties of faces will be called parallel (II) and oblique (I). During crystal growth in the [111] apparent symmetry 3 m also determined primarily by {111} facets, located on the periphery of the front at an angle of 19°28' to the axis of growth and generators when pulling the so-called track explicit faces (oblique faces). At the front of growth can present a face perpendicular to the axis of the crystal (I). Crystals oriented along the [110] mirror are parallel to the {111}, and crystals with [111] orientation - perpendicular to the face. Oblique faces were always primed straight or rounded layers.

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Regardless of the direction of stretching and an amplitude -frequency characteristics of development process of the power of the octahedral facets increased with increasing growth rate. This is clearly seen in the direct observation of crystal growth. Watching features morphology of crystals grown at different rates showed that the oblique faces on the surface of the crystals grown at higher rates were better developed. Almost all over the slowly growing crystal parallel faces out at all, they replaced the jog. In a system with small gradients on all geometrically possible crystal face {111} developed well in some places they intersect in straight edges, and in the crystal containing a rounded surface limitations clearly identify bottlenecks octahedral faces parallel to the axis of the crystal. Accidents on existing ideas are the result of periodic growth, due the rotation of the crystal in an asymmetric thermal field. When carrying out the method of crystal growth with perturbations at the interface it to a solid phase, the lateral surface is also composed of corrugations distinguishable to the naked eye. Clarity of their manifestations increased with the average growth rate (pullingspeed) and spans vibrations of the crucible with the melt and decreased with increasing frequency.

Investigation of the side surface of the crystals obtained standard method showed that these crystals had a more explicit discrete structure thin compared to the lateral surface of the ingot formed at fluctuations of the melt. Microscopic observation showed that such relief integral uniformity was determined that the "big" corrugations, each crest and trough which were repeated, not the case, as a general phenomenon for crystals grown at fluctuations of the melt at the solidification front. This phenomenon indicating apparently, a reduction of stress and a kind of "cover", which would be concluded as the cooling after the formation of the crystal.

Observation of many paintings etched with all the nuances that are difficult to convey when photographing samples, suggesting that the ability to detect the impurity inhomogeneity in large measure determined by the stress fields in the crystal. These residual stresses are correlated with the density of dislocations in crystals, but compliance is ambiguous, since the nature of the dislocation " preserved the " thermomechanical situation in which the crystals were at sufficiently high temperatures during their formation.

3. INFLUENCE OF AMPLITUDE-FREQUENCY CHARACTERISTICS OF CRYSTAL GROWTH PROCESSES TO CHANNEL HETEROGENEITY AND BANDED STRUCTURE

In the experiments started from the hypothesis that all fluctuations with macroscopic amplitudes melt during crystal formation will lead to the emergence of a well-defined layers of it. The bases for these assumptions were theoretical work on the effect of vibrations on the crystallization front entry of impurities into the growing crystals from the melt, as well as the few published experimental materials. In ourexperiments these«labels» are identified in crystals only in rare cases, when the oscillation frequency of the crucible with the melt were small (approximately 10 min^{-1}), and the amplitudes are sufficiently large (more than 1 mm scale). If these conditions on the detected diameter of the crystals of any banding in increments equal to the growth rate with respect to the frequency fluctuations in the relatively small diameter crystals (up to 10 mm), it can clearly be seen on the entire cross-section on the large-diameter portions crystal clear bands were detected with a pitch, usually at the periphery of the crystal. The nature and intensity of these bands depended on the magnitude of oscillations, as well as growth rate and shape of the growing crystal – in the case of restrictions of the crystal bands were detected clearly. In a reflow stripes are observed only at a peripheral portion of small diameter of the crystal when the scale exceeds 1.5 mm. In the field of fusion crystal dramatically change the curvature of the front, and occasionally found etched strongly related areas, apparently with the rapid crystallization of some of the peripheral regions of the crystals and, as a consequence, increased capture impurities.

For all crystals, regardless of the amplitude- frequency characteristics of impact, so-called rotational formed striations (Fig. 1).

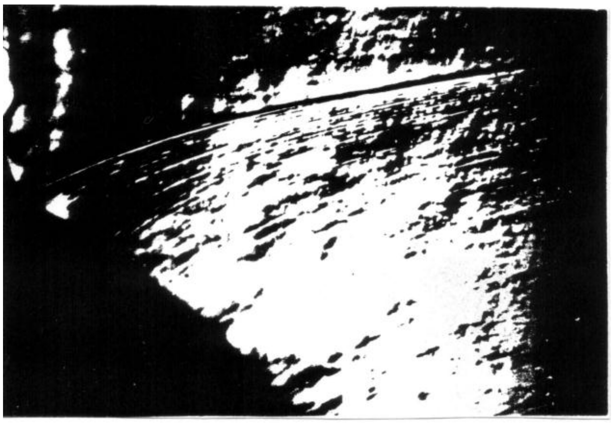

Fig. 1 – Strips at the periphery of the ingot growth associated with the rotation of the crystal

Their step determines the rotational speed and crystal pulling. The reasons for these irregularities have been found in a number of papers, the asymmetry of the thermal field of the melt. When low-frequency perturbations melt these bands easily viewed against the background of longer-wavelength vibrational bands. The upper inside portion of the single crystal stripes with a pitch of about 450 microns rotational bands were visible with 65 microns pitch and the lower portion etched only these rotational bands. All viewed crystals intensity and vibrational and rotational bands first decreased from the periphery to the center of the crystal, and then increased. Band channels in real crystals oriented with growth in the [111]. They have a more complicated structure is often interrupted as the standard for crystal formation and growth vibration.

As described above, large diameter crystals are often not able to identify the banded structure. One of the possible reasons for this in our opinion can be antiphase addition of rotational and vibrational bands . In no case it has not been possible to identify pure vibrational bands, if the frequency of vibrations of the crucible to melt below 20 min^{-1}. Most often in these cases, there is a kind of bitmap pictures – set of vibrational and rotational bands gave superposition picture with antinodes, a step which was sometimes very large (more than 1.5 mm). Within these antinodes only struggled to find strong diffuse bands with smaller increments.

Duct heterogeneity are the most significant impurity inhomogeneity, one of the main causes of faults in the production of semiconductor crystals vintage. It is known that the occurrence of irregularities of this type is due to the crystallization yield at the front portions of the macroscopic plane of the {111}, capture the impurities which are usually much higher than the adjacent surface portions of the rounded section. The flat portions of the {111} can arise only on bumps crystallization front. If concave front macroscopically perpendicular to the growth direction (111) face may show only at the periphery of the frontItalways isat least portion of the microscopic size of positive curvature. Such a face when pulling forms peripheral channel. When microscopically direction perpendicular convex front face octahedral growth leads to the formation of the central channel. All oblique face {111} for purely geometrical reasons, usually permanently growing crystals are present only at the periphery of the crystal. They also form the channels that we have repeatedly observed in the present work on crystals oriented with growth on [110]. In some works, the authors recommended to create such conditions during the growth of the crystal in which the (111) evenly filled to the entire front of crystallization. Within the verge of impurity distribution is sufficiently homogeneous and therefore crystal folded only peculiar pyramid rise (111) – channel would have the perfect radial distribution of impurities. Other possible ways of dealing with the heterogeneity of the channel while maintaining a sufficient accuracy on the crystal orientation [111] is to reduce the size of the channel on the chip , which helps increase the temperature gradients in the system melt – crystal at their interface and enhanced smoothing effect impurity capture face, aided reduction in growth rate. This technique from a practical standpoint is disadvantageous because it reduces the efficiency of the process of growing.

The experiments were identified conditions under which face steadily filled the front and formed a homogeneous single crystal, but when the crystals were grown in a wide range of changing conditions , varied and uniformity. Depending on the impact of fluctuations in the drawing speed of the melt on channel size was different. When pulling speed of 0.1 mm/min change from the standard method to vibrational mode always led to the expansion of the central and peripheral narrowing channel. Opposite situation was observed in crystals elongated at a higher rate. Effect of amplitude and frequency of vibrations on channel size, apparently, not very much, although the above-noted trend is more clearly manifested at large values of these parameters. Changing the crystal diameter from 10 mm to 80 mm was also not significantly influenced this trend, though reflected in a more subtle banded structure.

4. STRUCTURAL DEFECTS AND LOW-FREQUENCY VIBRATIONAL EFFECTS

The studies of crystal growth in the conditions of low frequency vibrational effects were directed to find possibilities to increase the stability of single crystal growth and ensure uniform dopant distribution in the cross section of the single crystal.

By means of selective etching of the longitudinal sections of the dislocation distribution patterns of crystals, which when grown performed by multiple transitions from the "standard" method for drawing a different vibrational frequencies has been determined that portions of a length of 20-25 mm crystal grown in the oscillation mode, the melt crucible, separated smooth belts length of 5-15 mm, in the process of education which the melt is not perturbed (Fig. 2)

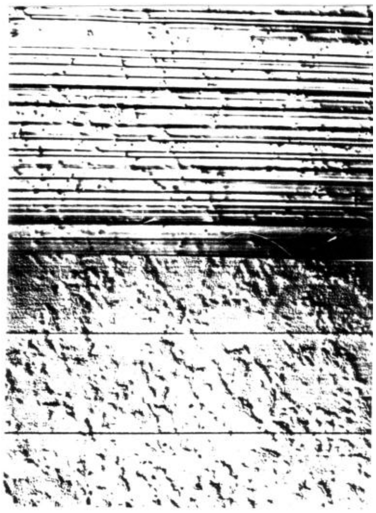

Fig. 2 – The transition from the oscillatory mode of growth (large band) to the standard (small growth bands)

In most cases, the transition from the standard to the oscillatory regime leads to a decrease in the density of dislocations. The degree of this reduction is dependent on the amplitude of the oscillations (large swings reduced dislocation density more efficiently) and the direction of stretching. When pulling the crystals in the [111] in the vibrational mode frequencies of 5-20 min^{-1} managed to reduce the dislocation density is approximately 2-3 times. Relative dislocations identified in cross sections of the crystals obtained in a series of experiments to study the dependence of the effective distribution coefficients of impurities on the amplitude and frequency parameters of the drawing process for the [100], it was noted that the standard processes of growing density of dislocations in crystals was generally higher than in conducted at the same rates "vibrational" processes. In standard cultivation, moreover, frequently observed in the macroscopic inhomogeneity of distribution of the dislocation pits character in cross-section and length of the crystal. Typical heterogeneity encountered in building dislocations in the bands (lines) and slip in low-angle boundaries.

It is known that slip dislocation occurs most rapidly over the vertical system {111} parallel to the growth direction so that a diamond-shaped pattern of etch pit, wherein 2 mm symmetry corresponds sided symmetry stretching direction. The maximum dislocation density in this case was observed "at the apices" of the diamond at the intersection of the individual systems of slip lines and areas on the periphery of the crystal, adjacent to the "parallel" {111} faces on the lateral surfaces contain little dislocations. This provision applies to those cases where dislocations are arranged in explicit slip lines, and a crystal in the cross section is almost a perfect circle.

In general, the study of structural defects in the crystals obtained in harsh heat conditions, showed that in this case, low-frequency disturbance of the melt at the interface reduces the average density of dislocations due to the periodic melting of crystallization and partially "heal" the defective portions of the crystals.

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