FEATURES IN THE KINETICS OF LATERAL ZONE CRYSTALLIZATION OF SEMICONDUCTOR CRYSTALS IN A TEMPERATURE GRADIENT FIELD


Theoretical and experimental investigations of the kinetics of a lateral zone crystallization process in a temperature gradient field are given. Kinetic rules for the method are established which allow one to control the rate of the process and the configuration of the crystallization channel.

Lateral zone crystallization (LZC) is a version of the method of zone crystallization in a temperature gradient field (ZCTG) [1]. The first LZC method was proposed by Kleinknecht and was realized on the basis of a planar zone in the InAs–In system [2]. Further development of the LZC method was reported in [3, 4] where the possibility in principle of using it for silicon and germanium was shown.

The LZC method is realized according to the following scheme (Fig. 1): between two crystalline plates 1 and 2 placed “side-by-side” a liquid zone 3 of the solvent-melt (Fig. 1a) is formed. The arrangement features a temperature field gradient G which is perpendicular to the plane of the plates. In the colder part of the zone there is crystallization and the surplus material of the zone is gradually pushed out from the hot part of the plates (Fig. 1b). Upon completion of the LZC process the plates 1 and 2 are monolithically joined by the crystallized channel 4 of a certain configuration doped by the material of the zone (Fig. 1c). The excess of the zone-forming material 5 on the side of the plates facing the heater is easily removed by a mechanical treatment.

Thus the basic difference of the LZC from the ZCTG method is that the temperature gradient lies not perpendicular to the flat layer of the solvent melt but parallel to it. Here the possibility of using a liquid zone of unlimited size in the direction of crystal motion makes it attractive to use the LZC method in physical investigations. For example one can investigate crystallization processes (especially in the initial states) and processes in the liquid phase (diffusion, convection) and processes at interphase boundaries. In applications the LZC method can be effectively used for formation of electrically heterogeneous structures in the bulk of a semiconductor crystal with given electrophysical properties, for welding of structural items made from semiconductor materials (for example silicon tubes of high temperature reactors), for monolithic joining of silicon crystals to produce lenses for infrared optics, etc. [1].

Together with this the effective use of the LZC method to realize the abovementioned processes is difficult by the consequence of insufficient understanding of the process kinetics. For technological applications of the LZC method there is important value in the possibility of controlling the rate of the process and the configurations of the crystallization channel. Just this question is dealt with in the present paper.

We will consider a process in which the situation is simplified. At an arbitrary instant of time let there be a zone of rectangular cross section of height L and width l (Fig. 2). The thickness \( L_0 \) of the initial crystalline plate is usually tens of microns to several mm. If ignore the latent heat release at the interphase boundary then for a zone whose width is

\[
1 < \frac{l}{L_0} < \frac{L}{L_0}
\]

(1)
the temperature gradient $G$ in the liquid phase turns out to equal the temperature gradient $G_s$ in the uniform crystal plate, i.e., the liquid phase does not change the temperature gradient in the initial arrangement:

$$G = G_s. \quad (2)$$

In Eq. (1) $\lambda_l$ and $\lambda_s$ are the thermal conductivities in the liquid and solid phases. Under conditions typical of the LZC method the conditions of Eq. (1) are always satisfied with the exception of the final stages of the process where it is possible to satisfy a condition $t >> \lambda_l/\lambda_s$ L opposite to Eq. (1) and a relation $G = \lambda_s/\lambda_l$ $G_s$ is obtained for the temperature gradient in the liquid phase. We will assume that Eq. (1) is satisfied while we will use Eq. (2) for the temperature gradient in the liquid phase.

Neglecting the effect of interphase kinetics and considering the limiting processes of the diffusion method in the liquid phase, we find the expression

$$\nu = \frac{i \frac{G}{C_s - C_l} dC}{dC} \quad (3)$$

for the crystallization rate (the velocity of the LZC method) where $D$ is the diffusivity in the liquid phase, $C_s$ and $C_l$ are the concentrations of the crystallizing material respectively in the solid and liquid phases, and $dC/dT$ is the slope of the liquidus line. Using the ratio between the temperature gradients in the liquid and solid phases for planar and linear zones [1] we can use Eq. (3) to establish a relation between the BZT velocity and the velocities of motion $\nu_0$ of planar and $\nu_1$ of linear zones in the ZCTG diffusion region:

$$\nu = \frac{\lambda_l}{\lambda_s} \nu_0, \quad (4)$$

$$\nu = \frac{\lambda_s + \lambda_l}{2\lambda_s} \nu_1. \quad (4*)$$

In view of the typical values of $\lambda_l$ and $\lambda_s$ we can conclude that the velocity in the LZC method is several (3-5) times higher than the ZCTG velocity under standard conditions.

Relation (4) can be used to determine the thermal conductivity of the solvent-melt. In a number of cases determination of $\lambda_s$ using (4) and (4*) can turn out to be more convenient than determining it from a comparison of the rates of motion of planar and perpendicular zones [1].

We will assume a crystallized layer of thickness $dx$ after a certain time interval $dt$ (Fig. 2). Here the height, width, and average concentration of the zone-forming material changes respectively by $dL$, $dl$, and $dC$. For a segregation coefficient $K < 1$ assuming mass balance we get the relation:

$$C_l dl + C_l (1 - K) dL + L dC = 0. \quad (5)$$

With $K > 1$ crystallization also occurs on the vertical walls of the growing cell (the value of $dl$ is negative) therefore mass balance leads to a relation somewhat different from Eq. (5)

$$C_l (1 - K) dl + C_l (1 - K) dL + L dC = 0. \quad (5*)$$

Equations (5) and (5*) allow one to study the kinetics of the LZC process as a function of its conditions.

We will consider several cases.

The simplest LZC method is realized with a constant temperature $T = \text{const}$. Here the concentration in the zone is also constant, i.e., $dC = 0$. From Eq. (5) one obtains the differential equation

$$L dl + (1 - K) dL = 0,$$

and in solving it we find

$$L = \nu C = \text{const}. \quad (6)$$