OPTIMIZATION OF THE GROWTH CONDITIONS OF A $Nd : YVO_4$ CYLINDRICAL BAR

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ABSTRACT

The main purpose of this paper is to find those values of the growth process parameters (pulling rate v, temperature at the meniscus basis T_0, die radius r_0) which assure the growth of a $Nd : YVO_4$ cylindrical bar with a prescribed diameter $2r_f$and for which the non-uniformities of the surface of the bar, due to small uncontrollable oscillations of the pulling rate and the melt temperature at the meniscus basis, are minimum possible. Numerical results ar given for cylindrical bar of 5 (mm) diameter, grown in a furnace in which the vertical temperature gradient is $k = 33$ (K/mm) for the following three type of uncontrollable oscillations: $\Delta v = 0.001$ (mm/s), $\Delta T = 1$ (K); $\Delta v = 0.01$ (mm/s), $\Delta T = 10$ (K) and $\Delta v = 0.02$ (mm/s), $\Delta T = 20$ (K), respectively.

INTRODUCTION

Oxide cylindrical monocrystals grown from the melt by dege-defined film-fed growth (E. F. G.) method are used as solid-state laser hosts and materials for acousto-opto-electronic devices. The shape and the quality of the crystal grown by E. F. G. method are determined by the shape of the meniscus (the liquid bridge retained between the crystal and the die) and its behavior during the growth. In the last 20 years many experimental and theoretical studies have been reported regarding this growth process (Refs. [1, 5]). The E.F.G. method is performed to achieve crystals with constant radius when the pulling rate v and the melt temperature T_0 at the meniscus basis are constant and the bottom line of the melt/gas meniscus on the die is fixed to the inner or outer edge (Refs. [6]). In reality the pulling rate v and the melt temperature T_0 can have small uncontrollable oscillations around an average value.

THE MATHEMATICAL MODEL

In this paper we consider the nonlinear mathematical model:

$$\begin{cases} \frac{dr}{dt} = -v \tan\left(\alpha(r, h, r_0) - \alpha_1\right) \\ \frac{dh}{dt} = v - \frac{1}{\Lambda \rho_2}[\lambda_1 G_1(r, h) - \lambda_2 G_2(r, h)] \end{cases} \tag{1}$$

which permits to compute the evolution in time of the radius $r = r(t)$ and the meniscus height $h = h(t)$.
In Eqs. (1): v - pulling rate; α_e - growth angle, $\alpha_e = \pi/2 - \alpha_1$; $G_{1,2}$ - temperature gradients in the melt and in the crystal, respectively; Λ - latent heat; $\rho_{1,2}$ - density of the melt and of the crystal, respectively; $\lambda_{1,2}$ -

thermal conductivity coefficients in the melt and in the crystal, respectively; $\alpha(r,h) < \pi/2$ - the angle between the Or axis and the tangent to the meniscus in the point (r,h).
In order to grow a cylindrical bar with constant radius, the following system:

$$\begin{cases} -v\tan\left(\alpha(r,h,r_0)-\alpha_1\right)=0 \\ v-\frac{1}{\Lambda\rho_2}[\lambda_1 G_1(r,h)-\lambda_2 G_2(r,h)]=0 \end{cases} \tag{2}$$

has to be satisfied. System (2) has two solutions (r_1,h_1) and (r_2,h_2) with $r_1 < r_2$. The steady state (r_1,h_1) is not stable but the steady state (r_2,h_2) is asymptotically stable. In the following the asymptotically stable steady-state (r_2,h_2) will be denoted by (r^*,h^*). The asymptotically stable steady-state (r^*,h^*) depends on v, on T_0, and on r_0. In order to determine these dependences we consider several values of the die radii r_0 in the range $(r_f;1.6r_f]$ and for each of them we find the set $S(r_0)$ of those couples (v,T_0) for which the grown crystal radius is equal to a desired radius r_f . For each die radius r_0 we find that couple (v,T_0) from $S(r_0)$ for which the amplitude A of the change of r_f, due to small oscillations of v and T_0, is minimum. Finally we identify that die radius r_0 and that (v,T_0) couple for which the amplitude A is minimum possible.

NUMERICAL RESULTS

Numerical results are given for a $Nd:YVO_4$ cylindrical bar of 5 (mm) diameter, grown in a furnace in which the vertical temperature gradient is $k = 33$ (K/mm) for the following three type of uncontrollable oscillations: $\Delta v = 0.001$ (mm/s), $\Delta T = 1$ (K); $\Delta v = 0.01$ (mm/s), $\Delta T = 10$ (K) and $\Delta v = 0.02$ (mm/s), $\Delta T = 20$ (K), respectively.

CONCLUSIONS

In the above model it is possible to predict those values of r_0, v, T_0, for which small uncontrollable oscillations of v and T_0 cause minimal variations of the desired crystal radius r_f.

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