temperature distribution over the container height turns out to equal 140 W/m·deg.

Numerous computations were performed by the programs developed in order to clarify the general regularities of the thermal aspect of obtaining refractory single crystals by directional crystallization. It is established that the crystallization front alters its position in space during crystal growth, in which connection the rate of crystal growth differs from the rate of container displacement. The expediency of shielding the container outside the heater zone is shown. The influence of the geometric and model factors on the process is clarified. Conclusions obtained from a computation by the programs are verified by results of an experimental investigation of the process. They are used to obtain refractory single crystals and their operating mode upon improvement of the apparatus.

NOTATION

T, temperature; x, space coordinate; u, perimeter; f, cross-sectional area; F, melt surface area; b, crystal height; l, crystal width; s, system shift from the initial position; y, position of the crystallization front measured from the forward endface of the boat; w, velocity; α, heat-exchange coefficient; ε_{re}, reduced coefficient of radiant exchange; ρ, density; L, heat of the phase transition; λ, heat-conduction coefficient. Subscripts: cr, crystallization; me, melting; en, surrounding medium (environment); m, melt; ef, effective.

LITERATURE CITED

1. Kh. S. Bagdasarov and L. A. Goryainov, "Experimental investigation of the temperature and heat flux distribution in apparatus to obtain single crystals by the vertical directional crystallization method," Inzh.-Fiz. Zh., 29, No. 6, 1109-1110 (1975).
2. Kh. S. Bagdasarov and L. A. Goryainov, "On an analytic investigation of heat-transport processes in an apparatus to obtain single crystals by the vertical directional crystallization method," Fiz.-Khim. Obrab. Met., No. 1, 73-78 (1978).

SOME FEATURES OF THE DISCHARGE IN AN ION SOURCE BASED ON A PENNING CELL

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Results of investigating the operating regimes of a Penning cell in the absence of a magnetic field are discussed.

The effect of a hollow cathode in a Penning cell type source is described in [1] and the dependence of the boundaries of its existence on the cavity length is investigated. In the interests of the possible application of this effect to obtain different polarity beams at the output, we investigated the dependence of the Penning cell operating regimes on the discharge intensity, the magnitude of the limiting resistance R_{lim}, and the electrode geometry.

Structurally, the source is executed in conformity with the recommendations in [1, 2]. Its schematic principle is presented in the figure. The anode and both cathodes are fabricated from tungsten. The working gas Ar was delivered by a metallic pipe of length $l = 0.15$ and diameter $d = 3\cdot10^{-3}$ m. In contrast to [2], a negative potential was given to the cathode 2 from a separate supply source. There was no magnetic field. The length of the cavity in the cathode (actually the length of the gas delivery tube) was selected to be greater than required to maintain the relationship between cavity length and cross section necessary for stable operation.

Analysis of the current–voltage characteristics of the discharge from the extended zone of the anode ($l = 2\cdot10^{-2}$, $d = 8\cdot10^{-3}$ m) obtained for the values $R_{lim} = (2-10)\cdot10^5\ \Omega$ and $p = 1.3-4$ Pa showed that high-voltage, weak-current ($I_p = (1-10)\cdot10^{-3}$ A; $U_p = (1.5-5.0)\cdot10^3$

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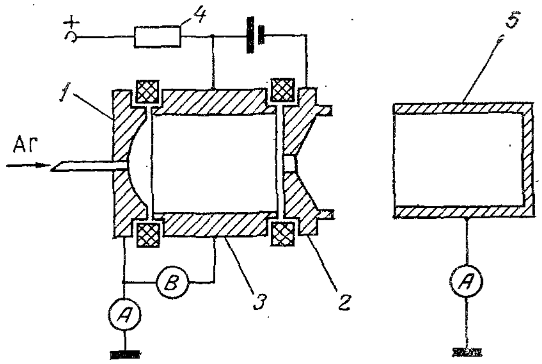

Fig. 1. Ion source diagram: 1, 2) cathodes; 3) anode; 4) resistor; 5) Faraday cylinder.

V) and low-voltage, heavy-current ($I_p = (10\text{-}100)\cdot10^{-3}$ A; $U_p = 400\text{-}600$ V) regimes exist, each of which can exist stably in the mentioned discharge-current and voltage domains for $R_{lim} = 4\cdot10^5\ \Omega$ and $p = 2.4$ Pa. The passage from one regime to the other can hence be accomplished by changing the voltage of the supply source.

An intense (hundreds of microamperes) electron beam with a 20' angle of dispersion is formed at the source output during the high-voltage discharge. The beam polarity changes with the passage to the low-voltage regime, and the intensity diminishes to tens of microamperes.

The discharge singularities observable in experiments (the increase in cathode 1 surface erosion as the discharge power grows, the dependence of the regime on the supply source voltage, and the change in beam polarity) can be explained as follows. For a definite value of the discharge power ($\sim$10 W), favorable conditions appear for the high-voltage, low-current effect of the hollow cathode, formed by the gas supply tube and the anode. In the case of an extended anode zone, the influence of the potential of electrode 2 (2 kV), on the electron beam formed by the cavity is insignificant because of anodic shielding, and an intensive electron beam is recorded at the source output. As the discharge power increases, the passage to a low-voltage, high-current regime is accomplished, accompanied by a voltage drop to 400-500 V in the anode–cathode 1 discharge gap. Consequently, the anodic shielding of electrode 2, whose field extracts ions from the discharge by exerting a braking effect on the electrons, is reduced.

As a result of an investigation of the dependence of source operation on anode geometry, it is established that the high-voltage discharge regime is not realized within the limits of the parameter values selected upon making the transition from the extended to the annular shape ($l = 5\cdot10^{-3}$, $d = 8\cdot10^{-3}$ m). In practice, the characteristics of the low-voltage discharge remain as before.

The singularities of Penning cell operation that appear for the electrode geometry described (extended anode zone) can be utilized to obtain beams of different polarity in one source. Such a source can be used for ion implantation with subsequent analysis by the electron or ion beams. Control of the beam composition is also possible because of the dependence of the quantity of material being atomized on the discharge power.

NOTATION

l, d, length and inner diameter of the electrode, respectively; p, pressure in the discharge chamber; U_p, discharge voltage; I_p, discharge current.

LITERATURE CITED

1. G. G. Vasil'eva and Yu. E. Kreindel', "Effect of a hollow cathode in a low pressure discharge of Penning type," Zh. S. Fiz., 34, No. 2, 298-301 (1969).
2. M. D. Gabovich, "Ion extraction from flame ion sources and primary ion beam formation (survey)," Prib. Tekh. Eksp., No. 2, 5-19 (1963).