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Research Article

LOCAL RESISTANCE OF HEATING MOLYBDENUM SHEET IN A TEST DEVICE

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ABSTRACT

Large demand for bulk of sapphire optical products, which are widely used as illuminators, optical windows in aviation and aeronautics etc., generates the inquiry of effective production of high quality industrial crystals. The technology of crystal growth with the horizontal single crystal sapphire crystallization method is based on putting the crystal seed into the front of the crucible resistant to temperatures up to 2150°C. Without encompassment of the production technology of this special container made from thin molybdenum sheet is not realistic to consider the productive exploitation of horizontal crystallization systems in engineering practice. This paper presents the analysis of the possibility of the local resistance of molybdenum sheet heating by its deep drawing to obtain better drawing properties by increased blank temperature.

Keywords: Molybdenum, resistance heating, deep drawing.

INTRODUCTION

The improvement of the optical and laser single crystals production technology from the melt of leucosapphire and yttria-allumina garnet (YAG) largely determines the success of the most important directions in the development of microelectronics, energy, optoelectronic and laser technology. The range of positive properties of sapphire monocrystalline is very wide - generation, amplification and transmission of electromagnetic waves. Such a widespread use of single crystal sapphire is possible due to their unique properties - high optical uniformity and clarity in a wide range of light wavelengths, radiation resistance and also high mechanical, thermal and dielectric properties [2, 13].

Especially for these products the horizontal single crystal sapphire crystallization method is suitable - the so called Bagdasarov method. The crucible made from molybdenum sheet is slowly moving in the vacuum passing the heating area, then the melting area and finishing in the cooling (crystallization) area. This method allows to create relative large single crystals with relative high velocity of grow (8-10 mm per hour) with precise shapes in more crystallographic directions [5].

The success of the described method depends on the shape of the molybdenum crucible, its adhesion to single crystal surface and its fast and repeatable production. Possible shapes of the crucible made from molybdenum developed for the Bagdasarov method are shown in Fig. 1. The simulation of a round and a simple-shaped rectangular cup deep drawed from molybdenum blank, which can be used by the drawing simulation of a more complex crucible shapes, is described in [24].

The development of thermal deep drawing system with vacuum environment for difficult-to-deformation materials was described in [15]. The molybdenum blank is deep drawed in a vacuum chamber, which is heated by the die tools and workpiece in the furnace by controlling the current, which were energized with delta connection. The automatic temperature control was realized using thermostat and temperature sensors, which

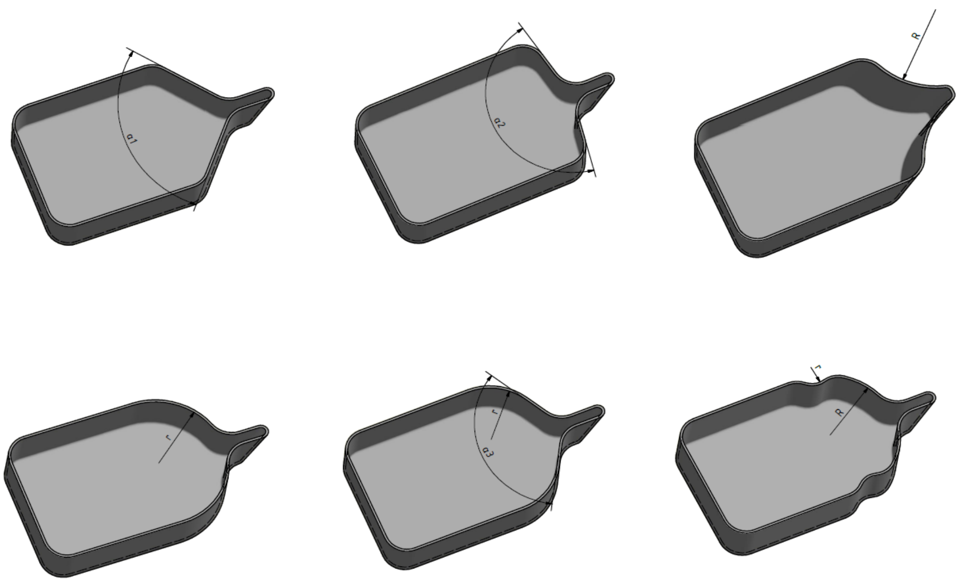


Fig. 1. Possible shapes of crystallization crucible made from molybdenum

transferred the control signal to the power controllers for regulating the current.

Meng et al. also described the drawability and frictional behavior of pure molybdenum sheet in deep-drawing process at elevated temperature in [16]. The results show the drawing force curves between simulations and experiments under lubricated condition at temperatures of 993, 1043, 1093 and 1143 K.

The investigation to production of a molybdenum container to growth single crystals by deep drawing process according the Bagdasarov method is described in [1]. The most efficient lubricants for deep drawing of sheet molybdenum with heating to 350°C proved to be aqueous black-lead preparations. These preparations were applied on the heated blank. The lubricant dried up very quickly and the remaining dry thin graphite layer kept on the blank in the course of drawing.

MOLYBDENUM BLANK DRAWING PROCESS IMPROVEMENT

The influence of the temperature and lubricants to drawability of molybdenum sheet by cup tests are described in [14, 15]. A unified constitutive model for strain-rate and temperature dependent behavior of molybdenum usable for further research in the area of molybdenum deep drawing simulations are described in [8].

One of the possibilities of the molybdenum blank deep drawing process improvement is the blank electric resistance heating. The principle of the deep drawing device with blank local heating option is shown in Fig. 2.

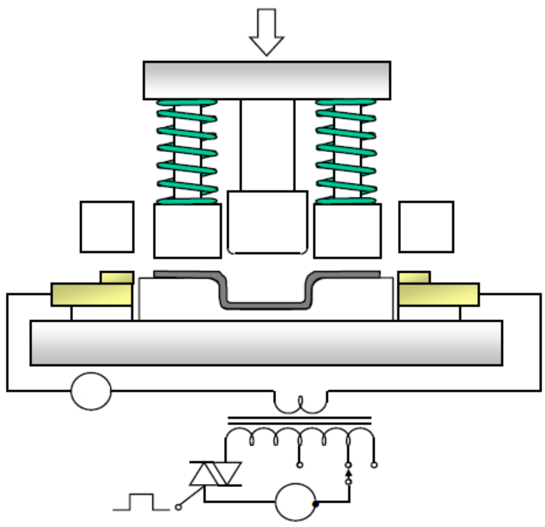


Fig. 2. Principle of the blank resistance heating by the drawing

Joule heating (also referred to as resistive or ohmic heating) in such a type of electric heating uses the process where the energy of an electric current is converted into heat as it flows through a resistance [20].

In particular, when the electric current flows through a solid or liquid with finite conductivity, electric energy is converted to heat through resistive losses in the material. The heat is generated on the microscale when the conduction

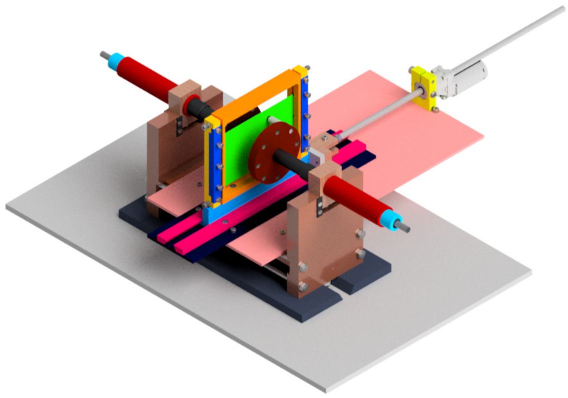


Fig. 3. Model of the molybdenum blank resistance heating test device

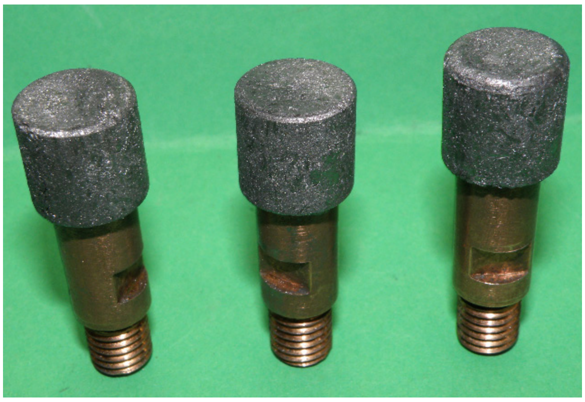


Fig. 4. Electric contacts (CuCoBe) with the graphite caps

electrons transfer energy to the conductor's atoms by way of collisions [3, 6].

The heat can be generated e. g. in resistance wires and it is transferred to the heated object by the conduction, convection and radiation [4, 21].

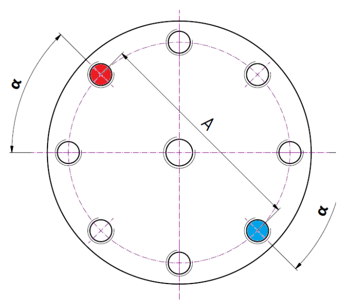
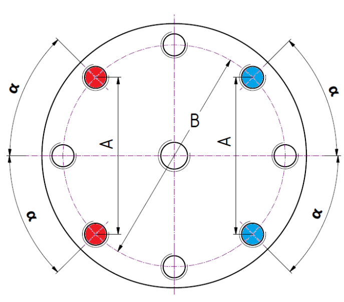
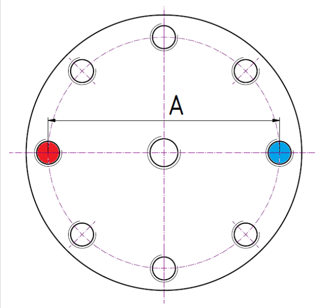
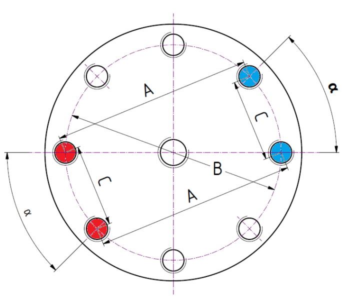
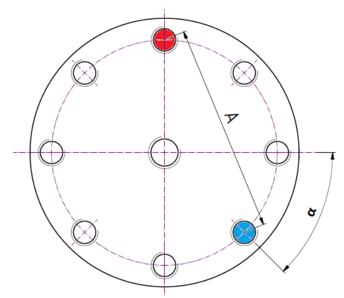
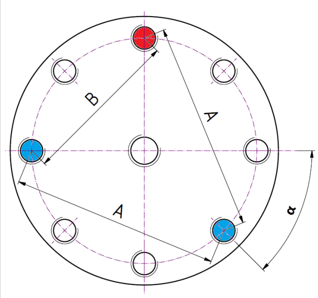
RESISTANCE HEATING TEST DEVICE

A test device shown in Fig. 3 was developed to test the electric resistance heating possibility of the moving molybdenum blank by a group of electrodes imprinted to the moving blank surface.

The device is designed as multi-point contact with exchangeable electric contacts following the thermodynamic heating demand by particular tests. Possible contact positions in the presented test device are shown in Table 1.

Electric contacts are manufactured from the copper alloy wide used in the industry applications with very good electrical conductivity and sufficient hardness and strength (CuCoBe CW104C) and graphite [12, 19]. The graphite is used in the form of caps installed at the CuCoBe contacts (Fig. 4).

Table 1. Possible contact positions and their characteristic parameters

Contact location			
Parameters	α = 45˚; A = 84 mm	α = 45˚; A = 59,4 mm B = 84 mm	α = 0˚; A = 84 mm
Contact location			
Parameters	α = 45˚; A = 77,6 mm B = 84 mm; C = 32,1 mm	α = 45˚; A = 77,6 mm	α = 45˚; A = 77,6 mm B = 59,4 mm

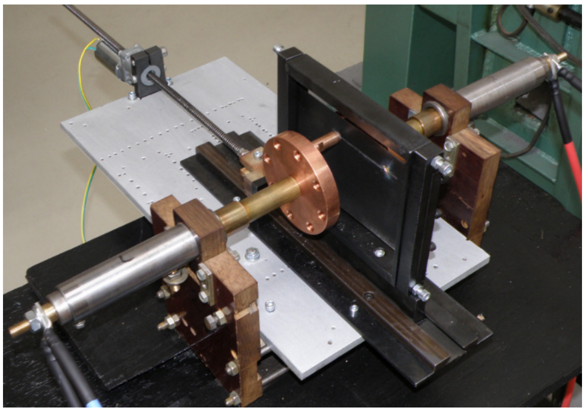


Fig. 5. Molybdenum sheet resistance heating test device

The speed of the moving molybdenum blank is controlled by the gearbox transferring the rotational speed of the motor [7] to linear motion with the speed value up to 5 mm·s^{-1}. The electric contact distance can be regulated by the regulation bolt [17]. The maximum of the blank - contact distance is defined to 15 mm. The chassis of the device is manufactured from the material, which insulates the electric contacts from the device body (Pertinax). The test device prepared to pilot tests is shown in Fig. 5.

PILOT MEASUREMENT CONDITIONS

The pilot measurements at the test device were done to verify the possibility of using such a heating system in the recent developed device for molybdenum sheet deep drawing [2, 13]. The pressure force generating springs had the stiffness of 0,45 N·mm^{-1}, the electric contacts characteristic parameters were α = 45°; A = 77,6 mm (Tab. 1). The input voltage by the zero blank motion was 2,55 V and increased by the applied electrical

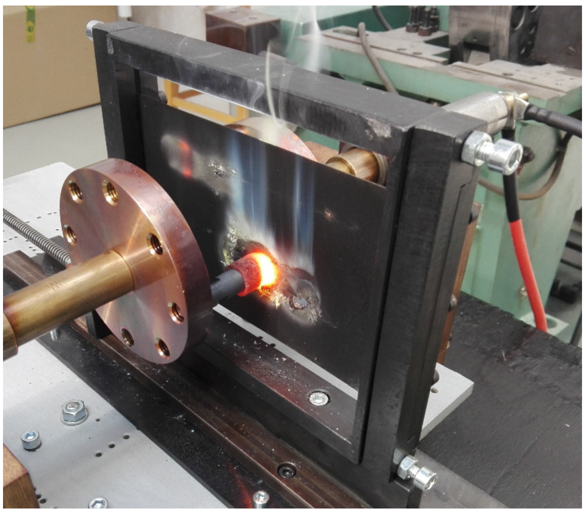


Fig. 6. Process of the resistance heating pilot test

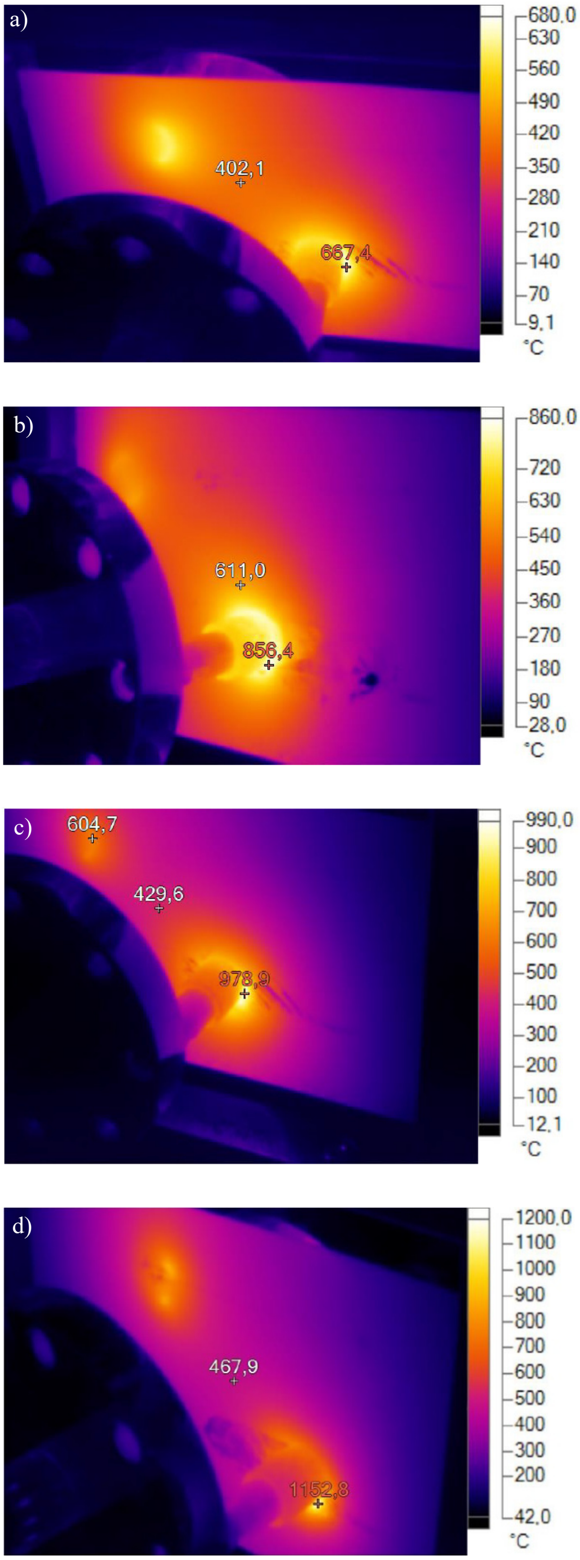


Fig. 7. Blank temperature progress in time t = 10 (a), 15 (b), 30 (c) and 60s (d)

load to 3,5 V. The input current was stabilized at the value of 472 A. Electric contacts were manufactured with the radius of 6 mm and capped by the graphite caps, the molybdenum sheet used in pilot tests had the thickness 0,5 mm.

PILOT TEST RESULTS

The temperature of the sheet was measured by the thermal camera Fluke Ti400 with the measurement scope from -20˚C to 1200˚C. First tests were done without the inert atmosphere and showed possible problems by this type of molybdenum blank heating (Fig. 6).

Measured data processed by Fluke Smart-View software by the test conditions described above are shown in Fig. 7.

In the time t = 10 s, the temperature in the place of the electric contacts rises up to 610 - 670˚C. In t = 15 s, the temperature value was about 810 – 860˚C and in t = 30 s the molybdenum sheet was heated to 930 – 980˚C. At the end of the test, the temperature reached 1152,8˚C and the space between activated electric contacts was heated to 467,9˚C (Fig. 7). In this phase of the test, the molybdenum blank oxidized heavy.

The temperature progress is shown in Fig. 8. After 15 s, the heating process was stabilized (2,55V, 472A) and the rise of the temperature is almost linear (~ 7,5˚C. s^{-1}).

SIMULATION OF THE LOCAL HEATING BY PILOT TEST CONDITIONS

The simulation of the local heating was done to predict the temperature distribution by variant electric contacts characteristics parameters. The simulation was done in the Comsol Multiphysics software. The local resistance heating is simulated by the Electric Currents and Heat Transfer in Solids interface in the AC/DC and Heat Transfer module. The parameters of the calculation model parts are described in Table 2.

The physics of the heat transmission of the modeled geometry surfaces is enhanced also by the by the Stefan-Boltzmann boundary condition for the heat radiation. The environment temperature is defined to 20˚C. The surfaces of the molybdenum sheet and graphite caps are defined by convective heat transfer boundary condition.

The physics of the electric currents is defined for the power terminal with the input power value

Table 2. Calculation model material parameters

Property (unit) / material	Mo	CuCoBe	Graphite
Density (kg·m^{-3})	10200	8850	1950
Specific heat (J.(kg·K)$^{-1}$)	250	420	710
Thermal conductivity (W·(m.K)$^{-1}$)	138	240	150
Electrical conductivity (S·m^{-1})	5·10^{6}	28·10^{6}	3·10^{3}
Relative permittivity (-)	1	1	1
Surface emissivity (-)	0,96	0,5	1

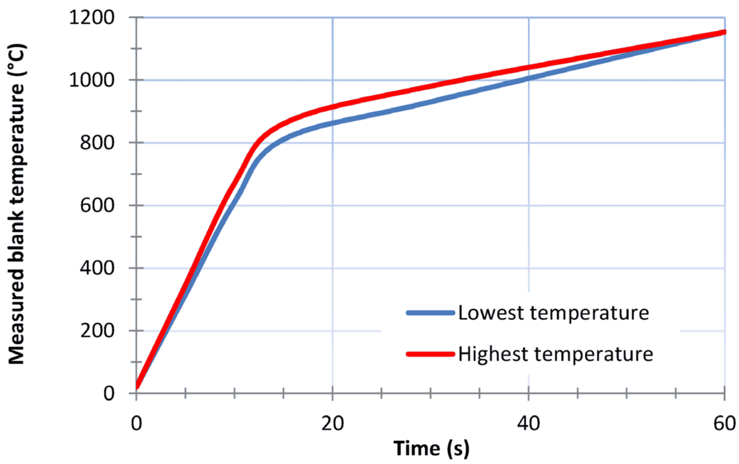


Fig. 8. Time progress of the lowest and highest measured temperature in the contact area

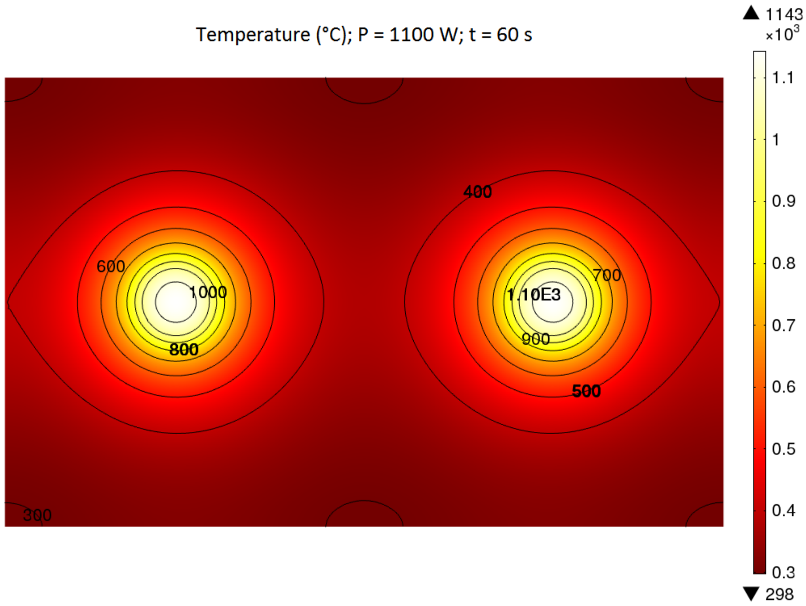


Fig. 9. Calculated temperature field of the molybdenum blank after 60s

P_0 = 1100 W, the voltage and the current are measured. The contact resistance between the graphite caps and the molybdenum sheet re is also modeled [22, 23]. The results of the resistance heating simulation after 60 s in the state of equilibrium is shown in Fig. 9.

The calculated temperature field with the highest value of 1143˚C showed sufficient correlation to the measured data (1152,8˚C) and verified the mathematical model with the power terminal.

CONCLUSION

The goal of the molybdenum blank resistance heating test device was to test particular conditions by the local heating of the molybdenum sheet. The tests were done to verify the possibility of using such a heating system in the recent developed device for molybdenum sheet deep drawing without the need of using a complex and expensive hot zone [9, 15, 18].

The pilot tests showed possible problems by this type of heating – the molybdenum sheet oxidized heavy after 60 seconds of the test start, which showed the necessity of the inert atmosphere usage and the precise heating and blank moving computer control by the development of heating module for a complex deep drawing device. The pollution of inert atmosphere of argon would influence the sheet surface morphology analogous to welding. From the point of view of the efficiency of the welding process and the properties of the executed joints, an appropriate choice of shield gas is extremely important. The most common choice is argon which is heavier than air and non-reactive. Its principal task is to protect the weld area against the ingress and unfavorable influences of impurities coming from the surrounding atmosphere [10].

The topographic inspection of the affected blank area can be done by the Infinite Focus Measurement Machine (IFM) or by X-Ray test by RTG or CT method described in [11].

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