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(54) GLASS MOULDING

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the transfer moulding of glass into optical elements.

The manufacture of finished optical elements from glass has long involved a series of complex, slow, and expensive separate steps such as preliminary moulding, shaping, grinding, polishing and centring. These techniques have been required because until recently no materials have been known which could be utilized to mould an optical glass into a finished optical element. Those materials which had suitable physical characteristics, such as strength, temperature stability and conductivity and non-adherence to glass, could not be provided with a surface finish which, on replication by the optical glass, resulted in acceptable moulded lenses. Those materials which could be provided with a suitable surface finish either adhered to the glass or had some other detrimental physical or chemical characteristic.

Our copending application No. 54745/71 (Serial No. 1,367,335) relates to the manufacture of image forming glass lenses by compression moulding of a glass within a glasslike carbon mould cavity.

The present invention provides a method and apparatus for the transfer moulding of glass from a transfer chamber made of a glasslike carbon into optical elements of a predetermined shapes in a mold cavity formed of glasslike carbon.

In accordance with the present invention, there is provided a method of moulding glass into glass elements comprising the steps of: providing at least two mould members rela-

tively movable between open and closed positions and formed of glasslike carbon, the mould members defining a transfer chamber for holding the glass and the mould members further defining in their closed positions mould cavities and sprues connecting said chamber and cavities; placing the glass within the transfer chamber; moving the mould members to their closed positions; heat softening the glass; applying pressure to the heat softened glass until the glass is transferred from the transfer chamber through the sprues into the mould cavities; cooling the moulded glass elements; moving the mould members to their open positions; and removing the moulded glass elements from the mould cavities.

Also in accordance with the present invention, there is provided apparatus for moulding optical glass into optical elements comprising: at least two mould members having open and closed positions and formed of glasslike carbon, the mould members defining a transfer chamber for receiving a glass, and further defining, when in their closed positions, mould cavities and sprues connecting the transfer chamber and the mould cavities; means for supporting the mould members and for moving the mould members between their open and closed positions; means for heating the mould members above the softening point of glass contained within the transfer chamber; and means for applying pressure to softened glass contained within the transfer chamber to transfer the glass from the transfer chamber through the sprues into the moulding cavities.

Also in accordance with the present invention, there is provided a mould for glass optical elements comprising at least two mould members formed of glasslike carbon and relatively movable between open and closed positions, the mould members defining a transfer chamber for holding glass, and the mould members further defining, in their closed position, a plurality of mould cavities

and sprues connecting the transfer chamber and the mould cavities to transfer glass from the chamber to the cavities.

5 In designing a lens for a particular application, the lens designer selects particular glasses having known optical properties and designs a combination of surface powers and separations which should result in a predicted optical performance. However, even the best optical design will not achieve its predicted performance unless the individual lens elements are manufactured and assembled under carefully controlled conditions. Of particular concern are two characteristics of each optical surface which are known in the art as surface quality and surface accuracy.

15 Surface quality relates to the finish of the lens, i.e. the distribution and size of such defects as scratches, digs, pits and "orange peel" appearance on the surface. The quality of the surface of a lens which is to be used in an optical system of the type used in photographic or equivalent apparatus must be high, and the term "high surface quality" is used herein to refer to a finished lens for such use. A lens having a "high surface quality" would not normally require any subsequent grinding or finishing operations.

20 Surface accuracy, which is also referred to as fit, pertains to the dimensional characteristics of the surface, i.e. the error between the measured radius of curvature and the design parameter, and the uniformity of the curvature of the surface. The degree of surface accuracy is generally measured by an interferometric comparison of a lens surface with a test plate gauge, by counting the number of Newton's rings produced by a specific wavelength of light and by examining the regularity of the rings. The degree of surface accuracy or fit of a lens at a specific wavelength is generally expressed as its power (the number of Newton's rings which are counted) and its irregularity (the difference between the number of rings counted in perpendicular directions across the fringe pattern). Lower figures for the power and irregularity indicate higher surface accuracy of the lens. Thus, a lens having "a high surface accuracy" or a "precise fit" is one which has dimensional characteristics which are extremely close to their design value and which are very uniform. The surface accuracy of a lens used in many applications in photographic apparatus is considered high when it has a power of less than 6 rings and an irregularity of less than 3 rings.

60 One factor which has impeded the development of a process for moulding finished glass lenses is the tendency of molten or softened glass to adhere to certain materials and to replicate accurately the surface structure of known mould material.

65 The development within recent years of

glasslike carbon materials has made possible not only our above-mentioned copending application, but also the present invention. It has been found that glasslike carbon can be polished to a glassy finish to which softened glass will not permanently adhere. In addition, the replication of such a surface by the glass has been found to leave the glass with a high surface quality. This group of carbons has been given the generic term "glasslike", because they exhibit a glassy surface appearance when polished. Glasslike carbons are prepared by the thermal degradation of organic polymers, and generally have a crystal structure with a maximum crystal size of 20A. They exhibit conchoidal fracture, have internal friction characteristics resembling glass more closely than normal graphite, and have gas impermeability comparable with that of glass. Glasslike carbons are known under a variety of names, such as the following: glass carbon, vitreous carbon, LMSC glassy carbon (Lockheed Corporation), Carbone Vitreux, vitro carbon and cellulose carbon. Glasslike carbon is chemically inert with many materials and it is isotropic. Further description of the chemical and physical properties of glasslike carbon as well as specific methods for preparing such a material will be found in United States Patent Specification No. 3,109, 712. Since there are no detectable crystal lattices or grain boundaries, it is possible to give the material the highly polished specular surface referred to above.

100 In order that the invention may be more clearly understood, embodiments thereof will now be described with reference to the accompanying drawings, in which:

105 Figure 1 is a partially cut away view of transfer moulding apparatus for producing optical elements according to this invention:

Figure 2 is a view showing the moulding apparatus of Figure 1 in a closed condition, just prior to moulding;

110 Figure 3 is a detailed view of a mould insert suitable for use in the moulding apparatus of the invention;

Figure 4 is a detailed view of an alternative embodiment of a mould insert suitable for use in the moulding apparatus of this invention; and

115 Figure 5 is a partially cut away view of an alternative embodiment of transfer moulding apparatus for producing optical elements according to this invention.

The apparatus illustrated in Figures 1 and 2 comprises a support assembly 10, a moulding chamber 12, an upper mould assembly 14, a lower mould assembly 16, a sealing assembly 17 and a press assembly 18. The support assembly 10 consists of a support member 20 on which are mounted support rods 22, stops 24 and a fixed upper support plate 26. A bottom support plate 28

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is provided with apertures 30 through which the support rods 22 extend so that the plate 28 may be moved in a vertical direction away from the stops 24 in a manner which will be described in more detail hereinafter.

The moulding chamber 12 is defined by a wall 32 which has a generally cylindrical shape and which is fixedly held between upper and lower mounting plates 34 and 36 by means of mounting rods 38. The wall 32 may be made of transparent material such as a synthetic plastics material or glass, or alternatively could be made of metal. Access is provided to the interior of the moulding chamber 12 by means of a vacuum line 40 through which the atmosphere in the chamber may be exhausted, a gas line 42 through which a controlled atmosphere may be introduced into the chamber and an exhaust line 44 to provide an exit means for the controlled atmosphere. Standard gas valves (which are not shown) may be attached to the lines 40, 42 and 44 to regulate the atmosphere present in the moulding chamber 12. A heating coil 46 is mounted outside the chamber 12 so as to surround the moulding area and to provide heat to the upper and lower mould assemblies 14 and 16. While the heating coil 46 is shown outside the chamber 12, this is done for ease of assembly. The coil 46 could be positioned within the chamber 12 and could also take any other form known in the art which will provide sufficient heat to the moulding chamber 12 to permit moulding of the optical glass contained therein.

The upper mould assembly 14 consists of a graphite base 50 and a mould insert 52 disposed on the lower face 54 of the base 50. The base 50 is fixedly mounted on the upper mounting plate 34 and extends downwardly into the moulding chamber 12 so as to be surrounded by the wall 32 and the heating coil 46. The lower mould assembly 16 consists of a graphite base 60 and a mould insert 62 disposed on the upper face 64 of the base 60. The mould insert 62 extends into the interior of the base 60 so as to form a transfer chamber 66. The base 60 is coupled to the movable bottom support plate 28 to enter into the moulding chamber 12 and to be brought into conjunction with the upper mould assembly 14 so that the mould inserts 52 and 62 define a moulding cavity therebetween. The mould inserts 52 and 62 will be described in more detail hereinafter.

The chamber 12 may be sealed by the sealing assembly 17 which comprises upper, middle and lower sealing plates 70, 72 and 74, a sealing ring 76 and bellows 78 and 80. The bellows 78 is disposed between the upper plate 70 and the middle plate 72 and is mounted on each to provide a vacuum seal. The bellows 80 is disposed between the

middle plate 72 and the lower plate 74 and is mounted on each to provide a vacuum seal. The plates 70, 72 and 74 and bellows 78 and 80 thus form a single unit for mounting within the moulding apparatus. When assembled, the upper plate 70 may be clamped or bolted to the plate 36 with the sealing ring 76 disposed therebetween in mating grooves so as to provide a vacuum seal. The middle plate 72 rests on the bottom support plate 28 and is movable therewith. The graphite base 60 rests on the middle plate 72 and is movable therewith so that the base 60 extends through central apertures in the plates 36 and 70 into the interior of the chamber 12. A ram 82 rests on the lower plate 74 and extends through the base 60 into the transfer chamber 66, terminating in a cap 68 formed of glasslike carbon such as is used for the mould inserts 52 and 62.

The press assembly 18 consists of chamber pistons 90 and a moulding press 92, each of which may consist of conventional pneumatic pistons such as are known in the art, or may be other hydraulic, mechanical or appropriate means for producing the desired movement. The chamber pistons 90 are mounted so as to bear against the support plate 28. The moulding press 92 is supported by the mounting plate 94, which is fixedly mounted on the middle plate 72 and supported by mounting rods 95 movable therewith. A ram 96 is movable within the press 92 so as to bear against the lower plate 74.

For assembly of the moulding apparatus, the plate 28 will be in its downward position, resting upon the stops 24. The sealing assembly 17 may now be positioned so that the plate 72 is resting upon the plate 28. The bellows 78 will be extending upwardly and will be supporting the plate 70 which will not yet be sealed to the plate 36. The bellows 80 will be extending downwardly, with the plate 74 resting on the ram 96 and the moulding press 92 supported by the plate 94. A glass gob may now be positioned within the transfer chamber 66.

The chamber pistons 90 may now be actuated to produce displacement of the support plate 28 in a vertical direction along the mounting rods 22. Upward movement of the plate 28 is continued until the plate 70 may be clamped to the plate 36 with the sealing ring 76 disposed in the mating grooves. Upward movement of the plate 28 causes the middle plate 72 to move upward, thereby moving the base 60 upwardly through the apertures in the plates 36 and 70 into the moulding chamber 12. Displacement of the base 60 under the urging of the chamber pistons 90 continues until the bases 50 and 60 are brought together with the mould inserts 52 and 62 aligned to form a mould cavity of the desired shape for pro-

duction of optical elements, as is illustrated in Figure 2. During movement of the base 60 upwardly, the bellows 78 will be compressed while maintaining a vacuum seal for the moulding chamber 12. After heating of the mould chamber 12, the moulding press 92 acts through the ram 96 to produce upward movement of the plate 74, thereby forcing the ram 82 upward while compressing the bellows 80 so as to maintain a vacuum within the chamber 12. Movement of the ram 82 forces the softened glass present in the transfer chamber 66 into the mould cavity formed by the mould inserts 52 and 62.

The mould inserts 52 and 62 and the cap 68 are made of a glasslike carbon, as is described hereinbefore, and the inserts may take either a parallel or a serial format as is illustrated in Figures 3 and 4. Figure 3 illustrates a form of the mould inserts 52 and 62 in which cavities 53 and 63 defined by the inserts 52 and 62 are in parallel, each of them receiving softened glass from the transfer chamber 66 at the same time interval after pressure is applied to the softened glass in the transfer chamber 66. It should be noted that, in the preferred practice of the invention, the transfer chamber and the sprues connecting the mould cavities with the transfer chamber are made of the same glasslike carbon as the mould inserts. This prevents contamination of the glass and minimizes stress variations which might result in strain in the molded optical element.

Figure 4 illustrates another form of the mould inserts 52 and 62 in which the mould cavities 53 and 63 are in series with softened glass entering the mould cavities at one point only and then flowing through each of the mould cavities serially until it reaches the last mould cavity. This arrangement is permissible with this apparatus because the mould inserts 52 and 62 are at substantially the same temperature as the glass contained within the transfer chamber 66.

Outlet sprues are provided in each type of insert to permit the atmosphere within the mould cavity to be evacuated and to permit excess glass to flow out of the mould cavity.

The glasslike carbon moulds have been illustrated as inserts on relatively sturdy graphite support members, which are present for heat transfer and to add strength and durability to the moulding apparatus. Moulding of finished optical elements could also be achieved in accordance with the invention in moulding apparatus which did not include supports or which had non-graphite supports.

Since heat softened glass replicates surfaces with which it comes into intimate contact, the surface of the cavity-defining walls are preferably rendered extremely smooth and dimensionally accurate. This can be

accomplished by grinding and polishing these walls until they reach the tolerance limits established for the final lens. As indicated previously, the "high surface accuracy" required of lenses of the quality used in photographic apparatus should frequently be within 6 Newton rings of power and 3 rings of irregularity. Surface accuracy well within these tolerances has been achieved in the walls defining the cavities of the glasslike carbon moulds. Likewise, these same mould walls preferably have "high surface quality", as is required of the finished lenses, which renders the walls substantially devoid of scratches, digs, pits and the like, and such surface quality has also been achieved in the practice of this invention. During these grinding and polishing operations, the mould cavities may also be configured to yield a finished optical element of a predetermined shape with a moulded mounting shoulder and the ridges and grooves associated with mounting seats. The walls defining the cavities are shaped much like the predetermined shape of the lens and lens shoulder to be produced by the mould, but provisions may have to be made for dimensional changes occurring in the moulded glass due to temperature changes and the like during and after the moulding process. Thus, the finished moulded element will be ready for final assembly without subsequent grinding and polishing.

According to a preferred method of moulding optical elements by this invention, a quantity of glass is placed within the transfer chamber 66. The glass must be shaped to fit within the chamber 66 but need not be preformed to a different volume and shape for different lens designs. Moreover, the surface of the gob need not be of high quality. The chamber pistons 90 are then actuated to move the plate 28 upwardly until the plates 36 and 70 may be clamped or bolted together with the base 60 extending through the apertures in the mounting plates 36 and 70. Movement of the plate 28 is then continued until the base 60 is brought into contact with the base 50, thereby defining a mould cavity between the inserts 52 and 62. The bellows 78 will be compressed while maintaining a vacuum seal, as is illustrated in Figure 2. The atmosphere within the chamber 12 may now be evacuated through the vacuum line 40, with the air in the mould cavity passing out through the outlet sprues. Simultaneously, heat is introduced into the chamber 12 by means of the heating coil 46 to degas the chamber 12 and the surfaces of the inserts 52 and 62 and the glass. The desired controlled atmosphere may now be introduced into the chamber 12 by means of the gas line 42 and the exhaust line 44. The heating coil 46 is again actuated causing continued

heating of the bases 50 and 60, the mould inserts 52 and 62 and the glass in the transfer chamber 66 until the desired moulding temperature is reached. The temperature of the inserts 52 and 62 may be monitored by thermocouples or other suitable means.

When the desired insert temperature has been attained, the glass and the inserts 52 and 62 will not be at substantially although not necessarily exactly the same temperature. The moulding press 92 may now be actuated to apply pressure to the softened glass in the transfer chamber 66 through the ram 96, the plate 74 and the ram 82, thereby forcing the glass out of the transfer chamber 66 and into the mould cavities defined by the inserts 52 and 62. After a suitable moulding time, the temperature of the mould will be reduced gradually to bring the temperature below the glass transformation point while still maintaining a load on the glass remaining in the transfer chamber 66, to prevent distortion of glass as the temperature is reduced.

After the glass transformation temperature has been reached, the load may be removed from the moulding press 92 and the moulds cooled further before separation, to prevent oxidation of the moulds. After a suitable time, the plates 36 and 70 may be unclamped and the chamber pistons 90 may be actuated to move in a downward direction, thereby permitting the base 60 to move away from the base 50 and permitting access to the optical elements for removal from the mould.

Specific conditions under which the process of this invention can be practiced are as follows:

With the chamber pistons 90 in their downward position and the plate 28 resting on the stops 24, an optical glass may be placed within the transfer chamber 66, after which the chamber pistons 90 are actuated to move the base 60 in an upward direction so as to enter the moulding chamber 12 through the apertures in the plates 36 and 70, the plates being clamped together to form a vacuum seal and the base 60 being brought into contact with the base 50 to form a mould cavity between the inserts 52 and 62;

the moulding chamber 12 is now evacuated by means of the vacuum line 40 to approximately 100 microns, and simultaneously degassing of the surfaces of the glass and the inserts 52 and 62 at a temperature which will not cause oxidation of the mould surfaces is accomplished by heating the moulding chamber 12 to between 200°C and 300°C by means of the heating coil 46;

the vacuum line 40 is now closed and a forming gas consisting of 95% nitrogen and 5% hydrogen is introduced into the chamber 12 through the gas line 42 with a slight over

pressure maintained by means of the exhaust line 44;

the power to the heating coil 46 is now readjusted to raise the temperature within the moulding chamber 12 until the glass is softened sufficiently to pass through the sprues from the transfer chamber 66 (for most glasses this requires a temperature between 700°C and 800°C and a time of approximately 5 to 20 minutes);

a load is now applied by the moulding press 92 to the ram 96, thereby pressing the cap 68 against the softened glass within the chamber 66 and forcing the glass through the sprues into the mould cavities defined by the inserts 52 and 62, the load applied being in the range of 50 psi to 5,000 psi and being applied for a time in the range of 1 minute to 20 minutes, with a higher load requiring a shorter loading time;

heating of the mould members is now terminated while a load is maintained on the ram 96 until a temperature below the transformation temperature of the glass being moulded is reached (for most optical glasses this will be a temperature between 550°C and 600°C);

the load on the ram 96 may now be removed and the temperature of the mould and glass elements allowed to fall to a temperature which precludes oxidation of the surface of the moulds upon opening the mould (preferably this temperature should be 300°C or less); and

the mould may now be opened by movement of the chamber pistons 90 in a downward direction with unclamping of the plates 36 and 70, and the finished moulded optical elements may be removed from the lower mould insert 62.

As a specific example of an optical element moulded by this process, a dense barium crown glass was moulded in the following steps: after introduction of the glass into the chamber 66, closing the chamber 12, degassing and introduction of the controlled atmosphere described above, the glass was brought to a temperature of 730°C in 10 minutes, the glass was then subjected to a load of 400 psi for 20 minutes, the mould and moulded element were then cooled for a period of 20 minutes to bring the temperature below 300°C, and the moulded element was then removed from the mould.

An alternative embodiment of moulding apparatus with which the moulding process of the present invention may be practiced is illustrated in Figure 5. The apparatus comprises a support assembly 110, a moulding chamber 112, an upper mould assembly 114, a lower mould assembly 116, and a press assembly 118. The support assembly 110 consists of a support member 120 on which are mounted support rods 122, stops 123, 130

and a fixed upper support plate 124. A bottom support plate 126 is provided with apertures 128 through which the support rods 122 extend so that the plate 128 may be moved in a vertical direction away from the stops 123 in a manner which will be described in more detail hereinafter.

The moulding chamber 112 is defined by a wall 130 which has a generally cylindrical shape, which may be transparent and which is fixedly held between upper and lower mounting plates 132 and 134 by means of mounting rods 136. The lower mounting plate 134 further defines a generally cylindrical aperture 138 and a shoulder 139 surrounding the aperture 138. Access is provided to the interior of the moulding chamber 112 by means of a vacuum line 140 through which the atmosphere may be exhausted from the chamber 112, a gas line 142 through which a controlled atmosphere may be introduced into chamber 112 and an exhaust line 144 to provide an exit means for the controlled atmosphere. Standard valves (which are not shown) may be attached to the lines 140, 142 and 144 to regulate the atmosphere present in the moulding chamber 112. A heating coil 146 is mounted within the chamber 112 so as to surround the moulding area and to provide heat to the upper and lower mould assemblies 114 and 116. While the coil 146 is shown and described as being within the chamber 112, it could also be outside so long as sufficient energy is supplied to the moulds to attain the required temperatures.

The upper mould assembly 114 consists of a graphite base 150 and a mould insert 152 disposed on the lower face 154 of the base 150. The base 150 is fixedly mounted on the upper mounting plate 132 and extends downwardly into the moulding chamber 112 so as to be surrounded by the wall 130. The lower mould assembly 116 consists of a base 160 and a mould insert 162 disposed on the upper face 164 of the base 160. The mould insert 162 extends into the interior of the base 160 so as to define a transfer chamber 166. The base 160 is of a generally cylindrical shape and is configured so as to pass through the aperture 138 in the lower mounting plate 134. The base 160 is fixedly mounted on the lower support plate 126 by means of a mounting block 168 which is configured to mate with the shoulder 139 and an O-ring (not shown) to provide a vacuum seal when the base 160 has passed through the aperture 138. The mould inserts 152 and 162 are made of glasslike carbon and may be of either the serial or parallel form as illustrated in Figures 3 and 4. The bases 150 and 160 are made of graphite.

The press assembly 118 consists of chamber pistons 170 and a moulding press

172, each of which may be conventional pneumatic pistons such as are known in the art or any hydraulic, mechanical or other appropriate means for producing the required movement. The chamber piston 170 act to produce displacement of the support plate 126 in a vertical direction along the mounting rods 122. Upward movement of the plate 126 causes the base 160 to be moved upward into contact with the base 150 thereby forming a mould cavity between the inserts 152 and 162. The moulding press 172 has a ram 174 which extends through the base 160 and which terminates in a top cap 167 which is formed of the same glasslike carbon as the inserts 152 and 162. The ram 174 extends through the base 160 so that the cap 167 is positioned as a bottom wall of the chamber 166. When the ram 174 is properly positioned, a glass gob placed in the transfer chamber 166 will be surrounded by glass like carbon surfaces. The ram 174 acts within the base 160 to force softened glass present in transfer chamber 166 into the mould cavity formed by the mould inserts 152 to 162.

Operation of the apparatus illustrated in Figure 5 is substantially the same as previously described with reference to Figures 1 and 2. With the plate 126 resting on the stops 123, a glass gob may be placed in the transfer chamber 166. The pistons 170 then operate to move the plate 126 upward, thereby moving the base 160 through the aperture 138 in the plate 134. Displacement of the base 160 and under the urging of the chamber piston 170 continues until the bases 150 and 160 are brought together with the mould inserts 152 and 162 aligned to form a glasslike carbon mould cavity of the desired shape for production of optical elements. A vacuum seal will be formed by the mating of the mounting block 168 with the shoulder 139 on the plate 134. The chamber 112 may then be evacuated with air escaping from the mould cavity through the outlet sprues and simultaneously heated by the coil 146 to outgas the chamber 112, inserts 152 and 162 and the glass in the chamber 166. A controlled atmosphere may now be introduced into the chamber 112 through the gas line 142 and exhaust line 144. When degassing is complete, the temperature in the chamber 112 is raised and maintained until the glass in the chamber 166 has been softened sufficiently for moulding. Pressure is applied against the softened glass by the press 172 through the ram 174 until the softened glass has flowed into the mould cavity. The temperature is then reduced below the glass transformation point, at which time the load may be removed and the mould cooled further until a temperature is reached which will not cause oxidation of the surfaces of the moulds. After a suitable

time, the pistons 170 may be withdrawn, permitting the apparatus to be opened for removal of the finished moulded optical element.

5 The invention has been described in detail with particular reference to preferred embodiments thereof but it will be understood that variations and modifications can be effected within the scope of the invention as defined in the claims. In particular, it should be noted that the apparatus shown is only exemplary of transfer moulding apparatus for operation of the present invention and other types of moulding apparatus in which different elements may be moved to define a mould chamber and a mould cavity may be utilized for practice of this invention.

20 WHAT WE CLAIM IS:—

1. A method of moulding glass into glass elements comprising the steps of: providing at least two mould members relatively movable between open and closed positions and formed of glasslike carbon, the mould members defining a transfer chamber for holding the glass and the mould members further defining in their closed positions mould cavities and sprues connecting said chamber and cavities; placing the glass within the transfer chamber; moving the mould members to their closed positions; heat softening the glass; applying pressure to the heat softened glass until the glass is transferred from the transfer chamber through the sprues into the mould cavities; cooling the moulded glass elements; moving the mould members to their open positions; and removing the moulded glass elements from the mould cavities.

2. A method as claimed in Claim 1, wherein the mould members and glass are preheated and a non-oxidizing atmosphere is established around the mould members and glass.

3. A method as claimed in Claim 1 or 2, also comprising the steps of cooling the mould members while applying pressure to the glass remaining within the transfer chamber until the temperature of the glass has been reduced below the transformation temperature of that glass, and removing the force from the glass and further cooling the mould members before moving the mould member to their open positions and removing the moulded elements from the mould cavities.

4. A method as claimed in Claim 1, 2 or 3, wherein the glass is heat softened at a temperature within the range of 700°C. to 800°C.

5. A method as claimed in any one of Claims 1 to 4, wherein the pressure applied to the heat softened glass is in the range of 50 psi to 5000 psi.

6. A method as claimed in any one of Claims 2 to 5, wherein the mould members and glass are preheated to a temperature of from 200°C. to 300°C.

7. A method as claimed in any one of Claims 2 to 6, wherein an atmosphere of 95% nitrogen and 5% hydrogen is established around the mould members and glass.

8. A method as claimed in any one of Claims 3 to 7, wherein the mould members are cooled to a temperature of from 550°C. to 600°C. while maintaining the pressure on the glass remaining in the transfer chamber.

9. A method as claimed in any one of Claims 1 to 8, wherein, after moulding, the pressure on the glass is removed and the mould members are cooled to a temperature not exceeding 300°C.

10. A method as claimed in Claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

11. A moulded glass element made by a method as claimed in Claim 1.

12. A moulded glass element made by a method as claimed in any one of Claims 2 to 9.

13. A moulded glass element made by a method as claimed in Claim 10.

14. Apparatus for moulding optical glass into optical elements comprising: at least two mould members having open and closed positions and formed of glasslike carbon, the mould members defining a transfer chamber for receiving a glass, and further defining, when in their closed positions, mould cavities and sprues connecting the transfer chamber and the mould cavities; means for supporting the mould members and for moving the mould members between their open and closed positions; means for heating the mould members above the softening point of glass contained within the transfer chamber; and means for applying pressure to softened glass contained within the transfer chamber to transfer the glass from the transfer chamber through the sprues into the moulding cavities.

15. Apparatus as claimed in Claim 14, further comprising means defining a moulding chamber surrounding the mould members and within which the mould members are movable to their closed position, and means for controlling the atmosphere within the moulding chamber.

16. Apparatus as claimed in Claim 14 and substantially as hereinbefore described with reference to Figures 1 to 4 of the accompanying drawings.

17. Apparatus as claimed in Claim 14 and substantially as hereinbefore described with reference to Figures 3, 4 and 5 of the accompanying drawings.

18. A mould for glass optical elements comprising at least two mould members formed of glasslike carbon and relatively

time, the pistons 170 may be withdrawn, permitting the apparatus to be opened for removal of the finished moulded optical element.

5 The invention has been described in detail with particular reference to preferred embodiments thereof but it will be understood that variations and modifications can be effected within the scope of the invention as defined in the claims. In particular, it should be noted that the apparatus shown is only exemplary of transfer moulding apparatus for operation of the present invention and other types of moulding apparatus in which different elements may be moved to define a mould chamber and a mould cavity may be utilized for practice of this invention.

20 WHAT WE CLAIM IS:—

1. A method of moulding glass into glass elements comprising the steps of: providing at least two mould members relatively movable between open and closed positions and formed of glasslike carbon, the mould members defining a transfer chamber for holding the glass and the mould members further defining in their closed positions mould cavities and sprues connecting said chamber and cavities; placing the glass within the transfer chamber; moving the mould members to their closed positions; heat softening the glass; applying pressure to the heat softened glass until the glass is transferred from the transfer chamber through the sprues into the mould cavities; cooling the moulded glass elements; moving the mould members to their open positions; and removing the moulded glass elements from the mould cavities.

2. A method as claimed in Claim 1, wherein the mould members and glass are preheated and a non-oxidizing atmosphere is established around the mould members and glass.

3. A method as claimed in Claim 1 or 2, also comprising the steps of cooling the mould members while applying pressure to the glass remaining within the transfer chamber until the temperature of the glass has been reduced below the transformation temperature of that glass, and removing the force from the glass and further cooling the mould members before moving the mould member to their open positions and removing the moulded elements from the mould cavities.

4. A method as claimed in Claim 1, 2 or 3, wherein the glass is heat softened at a temperature within the range of 700°C. to 800°C.

5. A method as claimed in any one of Claims 1 to 4, wherein the pressure applied to the heat softened glass is in the range of 50 psi to 5000 psi.

6. A method as claimed in any one of Claims 2 to 5, wherein the mould members and glass are preheated to a temperature of from 200°C. to 300°C.

7. A method as claimed in any one of Claims 2 to 6, wherein an atmosphere of 95% nitrogen and 5% hydrogen is established around the mould members and glass.

8. A method as claimed in any one of Claims 3 to 7, wherein the mould members are cooled to a temperature of from 550°C. to 600°C. while maintaining the pressure on the glass remaining in the transfer chamber.

9. A method as claimed in any one of Claims 1 to 8, wherein, after moulding, the pressure on the glass is removed and the mould members are cooled to a temperature not exceeding 300°C.

10. A method as claimed in Claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

11. A moulded glass element made by a method as claimed in Claim 1.

12. A moulded glass element made by a method as claimed in any one of Claims 2 to 9.

13. A moulded glass element made by a method as claimed in Claim 10.

14. Apparatus for moulding optical glass into optical elements comprising: at least two mould members having open and closed positions and formed of glasslike carbon, the mould members defining a transfer chamber for receiving a glass, and further defining, when in their closed positions, mould cavities and sprues connecting the transfer chamber and the mould cavities; means for supporting the mould members and for moving the mould members between their open and closed positions; means for heating the mould members above the softening point of glass contained within the transfer chamber; and means for applying pressure to softened glass contained within the transfer chamber to transfer the glass from the transfer chamber through the sprues into the moulding cavities.

15. Apparatus as claimed in Claim 14, further comprising means defining a moulding chamber surrounding the mould members and within which the mould members are movable to their closed position, and means for controlling the atmosphere within the moulding chamber.

16. Apparatus as claimed in Claim 14 and substantially as hereinbefore described with reference to Figures 1 to 4 of the accompanying drawings.

17. Apparatus as claimed in Claim 14 and substantially as hereinbefore described with reference to Figures 3, 4 and 5 of the accompanying drawings.

18. A mould for glass optical elements comprising at least two mould members formed of glasslike carbon and relatively



movable between open and closed positions, the mould members defining a transfer chamber for holding glass, and the mould members further defining, in their closed position, a plurality of mould cavities and sprues connecting the transfer chamber and the mould cavities to transfer glass from the chamber to the cavities.

19. A mould as claimed in Claim 18, where the mould members define a sprue between the transfer chamber and each of the plurality of mould cavities, whereby each cavity may simultaneously receive glass from the transfer chamber.

20. A mould as claimed in Claim 18, where the mould members define a sprue between the transfer chamber and a first

one of the plurality of mould cavities, and the mould members further define a sprue between each of the mould cavities and at least one other of the mould cavities, whereby the cavities may sequentially receive glass from the transfer chamber.

21. A mould as claimed in Claim 18 and substantially as hereinbefore described with reference to Figure 3 of the accompanying drawings.

22. A mould as claimed in Claim 18 and substantially as hereinbefore described with reference to Figure 4 of the accompanying drawings.

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