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(54) MANUFACTURE OF GLASS LENSES

(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 per-
 formed, to be particularly described in and
 by the following statement:—

This invention relates to the manufacture
 of glass lenses, and in particular to the
 moulding of glass into finished lens elements.

The manufacture of optical lens elements
 has long involved the use of painstaking
 procedures which are complex, slow and ex-
 pensive. Despite diligent efforts within the
 lens making industry to improve existing
 methods of lens manufacture, the conven-
 tional methods require many separate opera-
 tions. According to one method, a rough
 moulded glass blank is first made by heating
 a weighed chunk of glass to a plastic state
 and pressing the glass to the desired shape in
 a metal mould. The blank is necessarily
 larger than the intended finished lens ele-
 ment to allow for the removal of material,
 since the outer layers of the lens blank are
 often of low quality. The lens is shaped by
 a series of grinding operations, followed by
 a series of polishing operations. Then the
 lens shape is checked and corrections are
 made to ensure the proper shaping of the
 lens.

The lens is then centred by grinding its
 rim, so that its mechanical axis (defined by
 the edge of the lens) coincides with the
 optical axis (the line between the centres
 of curvature of the two lens surfaces).

Spherical lens surfaces are generated by
 rotating the blank in a vacuum chuck and
 grinding the blank with a rotating annular
 wheel whose axis is at an angle to the chuck

axis. It is considerably more complicated to
 produce non-spherical lens surfaces, and one
 problem is that grinding and polishing can
 easily destroy the basic shape of the lens.

The expense of existing methods for fab-
 ricating glass lenses has led to the limited
 use of plastics lenses. Synthetic plastics ma-
 terial has several advantages as a lens ma-
 terial, being light, shatterproof and mould-
 able. However, presently available plastics
 materials which are suitable for use as lens
 materials, such as polystyrene, polycyclo-
 hexyl methacrylate, and polymethyl meth-
 acrylate, are relatively soft and scratch
 easily. The latter material tends frequently
 to be hazy and sometimes yellowish. Also,
 the plastics materials usually soften within
 the range of 60° to 80°C and their indices
 of refraction may change in time. They
 absorb water and are subject to dimensional
 changes, and the high thermal expansion
 of the plastics materials causes changes in
 their indices of refraction to an extent ten
 times that of glass, thus severely impairing
 the optical performance of the lens.

Glass is thus clearly a more desirable
 material for lenses, but plastics lenses are
 considerably easier and cheaper to manu-
 facture than glass lenses because they can
 be mass produced by moulding. Existing
 moulding methods have not been suitable
 for the moulding of finished glass lenses
 because of the physical characteristics of
 glass and its tendency to adhere to some
 materials. United States Patent Specification
 No. 2,410,616 discloses a machine for
 moulding glass lenses which have an accur-
 ate "spectacle finish" on their surfaces, such
 a finish being defined as one resembling
 and closely approaching the finish of spec-
 tacle lenses. The lenses thus moulded always
 require finishing by grinding and polishing
 operations. Optical glass has been found to

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reproduce accurately the surfaces of those mould materials to which it does not adhere, and this tendency has heretofore made all of the previously known mould materials unacceptable for the moulding of glass lenses. For example, glass moulded in metal dies reproduces the grain structure of the mould material on the surface of the glass, and such lenses are unsuitable for use in photographic apparatus.

In order for a glass lens to be incorporated in a photographic apparatus or in any optical system requiring good image forming qualities, the lens must meet certain criteria. These criteria are very strict, which is the reason that the existing above-indicated carefully controlled lens fabricating processes are used. Some of these criteria relate to the nature of the glass itself and are not of interest here. What is of interest here is the nature of the surface of the lens. The lens surface is selected by the lens designer for a particular purpose, and not only must the parameters defining the lens shape be carefully conformed to, but the lens surface itself must be carefully controlled. The major characteristics of an optical surface are known in the art as surface quality and surface accuracy.

Surface quality relates to the finish of the lens, and a consideration of surface quality includes inspecting for such defects as scratches, digs, pits and "orange peel" appearance. Surface accuracy, which is usually specified in terms of the wave length of light of a specific colour, refers to the dimensional characteristics of the surface, i.e. the value and uniformity of the radius of curvature of the surface. The surface accuracy is generally determined by an interferometric comparison of the lens surface with a test plate gauge, by counting the number of Newton's rings, and examining the regularity of the rings. The surface accuracy of a lens is often referred to as its fit, which is expressed in terms of its power (the number of Newton's rings which can be counted) and its irregularity (the difference between the numbers of rings counted in directions at right angles to each other across the fringe pattern). Lower figures for the power and irregularity indicate a better lens.

The quality of the surface of a lens which is to be used in an optical system of the type used in photographic apparatus 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 therefore not normally require any subsequent grinding or finishing operations. Similarly, a lens having "high surface accuracy" or a "precise fit" is one which has dimensional characteristics which are extremely close to their design value and 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.

As stated previously, a factor which has severely hindered the development of a process for moulding finished glass lenses is the tendency of molten or softened optical glass to adhere to certain materials, or to reproduce accurately the surface structure of mould materials. We have found that lenses having high surface quality and accuracy can be moulded in moulds made from material which is chemically inert, which has no grain boundaries, and to which molten glass does not permanently adhere. When moulding surfaces are made from such a material, the surfaces having the high surface accuracy and high surface quality desired in the lens to be produced, satisfactory results can be achieved under proper conditions.

The development within recent years of certain carbonaceous materials has made possible the present development of a mould for glass lenses. These materials can be polished to a glassy finish to which softened or molten glass will not permanently adhere. This new group of carbons has been given the generic descriptive term "glasslike". Glasslike carbons are defined as those carbons prepared by the thermal degradation of organic polymers and having a crystal structure with a maximum crystal size of 20Å, exhibiting a glassy surface appearance, conchoidal fracture, internal friction characteristics resembling those of glass more closely than those of normal graphite, and gas impermeability comparable with that of glass. Glasslike carbons are known under a variety of names, such as the following: glassy carbon, vitreous carbon, LMSC glassy carbon (Lockheed Corporation), Carbone Vitreux, vitro carbon and cellulose carbon. Glasslike carbon is extremely chemically inert and it is isotropic. 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. The reproduction of such a surface by glass has been found to leave the glass with a high surface quality and a high surface accuracy.

The preparation of vitreous carbon is described in B.P. 860,342; 889,351 and by Davidson and Losty in the G.E.C. Journal of Science and Technology 30, 22 (1963).

The present invention provides a practicable method and apparatus for moulding finished glass lenses.

In accordance with the present invention, there is provided a method of moulding glass into an optical lens having a predetermined shape, wherein a portion of glass is placed between mould members having open and

closed positions, the mould members including glass-contacting surfaces formed of glasslike carbon (as hereinbefore defined) having a high surface quality and a high surface accuracy (as hereinbefore defined) and being shaped to define in the closed position of the mould members a cavity configured to produce a lens of said predetermined shape, the mould members are moved to their closed position until the glass in the mould cavity conforms to the shape of the cavity under the effect of heat and the application of pressure in a non-oxidizing atmosphere, the mould members are moved to their open position, and the moulded lens is removed.

In one embodiment of the invention, the mould members are preheated and the glass is softened before being placed between the mould members.

According to a preferred embodiment of the invention, the glasslike carbon mould is preheated and subjected to an inert or slightly reducing atmosphere, a portion of heat-softened optical glass is placed in the mould cavity, the mould is closed and subjected to a prescribed pressure which is maintained for a prescribed period of time, and the mould is opened and the finished lens removed.

According to another preferred embodiment of the invention, the glasslike carbon mould is located in an appropriate chamber, and the subsequent process steps comprise: inserting a glass gob in the cavity of the mould, evacuating the chamber, outgassing the mould assembly at a relatively low temperature, controlling the atmosphere of the chamber so that it is non-oxidizing, closing the mould, heat softening the glass gob by increasing the temperature of the mould, applying pressure to the mould, cooling the mould to bring the glass to a temperature below the glass transformation point, removing the pressure from the mould, further lowering the temperature of the mould, and removing the finished lens.

Both these embodiments require a glasslike carbon mould having a mould cavity which is configured to yield a finished lens of a predetermined shape and which is defined by glass-contacting surfaces having a surface quality and a surface accuracy comparable to that of the finished lens. The mould can comprise, for example, a pair of separable mould members having opposing walls which cooperatively define a mould cavity when the mould members are in their closed positions. The walls defining the cavity are shaped very like the predetermined shape of the lens to be produced by the mould, but provisions may have to be made for dimensional changes occurring in the moulded glass lens, resulting, for ex-

ample, from temperature changes during and after the moulding process.

Also according to the present invention, there is provided apparatus for moulding glass into an optical lens having a predetermined shape, comprising mould members movable between open and closed positions and having glass-contacting surfaces formed of glasslike carbon (as hereinbefore defined) defining, when the mould members are in their closed position, a mould cavity configured to produce a lens of said predetermined shape, the glass-contacting surfaces having a high surface quality and a high surface accuracy (as hereinbefore defined) comparable with the surface quality and surface accuracy required of said lens, and means for establishing a non-oxidizing atmosphere around the mould members.

In one embodiment, the apparatus also comprises heating means for preheating the mould members, heating means for heat-softening an optical glass, and means for placing the heat-softened glass between the mould members.

In another embodiment, the apparatus also comprises heating means for heating the mould members above the softening point of optical glass to be used in the apparatus, means for controlling the temperature of the mould members, a chamber within which the mould members are movable to the closed position and within which the pressure and content of the atmosphere can be controlled, means for controlling the oxygen content of the atmosphere within the chamber, and means for urging the mould members together under a predetermined load. The means for controlling the oxygen content within the chamber may comprise means for evacuating the chamber, means for introducing forming gas to the chamber, and means for controlling the pressure of the gas.

Since heat softened or molten glass reproduces surfaces with which it comes in intimate contact, the surfaces of the cavity-defining walls must be rendered extremely smooth and dimensionally accurate. This can be accomplished by grinding and polishing these surfaces until they reach the tolerance limits established for the intended lens. As indicated previously, the surface accuracy of lenses of the quality used in photographic apparatus should frequently be within 6 Newton rings of power. Surface accuracy to well within this degree has been achieved in the walls defining the cavities of glasslike carbon moulds. Likewise, these same mould surfaces must have a "high surface quality" to the degree mentioned previously, which renders them substantially devoid of defects such as scratches, digs and pits.

The glasslike carbon mould members are preferably installed as inserts on sturdy sup-

port members, such as graphite support blocks, in order to add strength and durability to the mould.

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

10 Figure 1 is a side elevation, partly in section, of a moulding apparatus for producing glass lenses in accordance with the present invention;

Figure 2 is an enlarged isometric view of the mould employed in the apparatus shown in Figure 1;

15 Figure 3 is a perspective view, partly cut away, of another moulding apparatus for producing glass lenses in accordance with the present invention;

20 Figure 4 is an enlarged isometric view of the mould employed in the apparatus shown in Figure 3; and

25 Figures 5A and 5B are partial cross-sectional views on the line V—V in Figure 4, showing the mould in two different stages of operation.

30 The apparatus shown in Figure 1 and in part in Figure 2 comprises a stationary mould assembly 1 fixed relative to a support member 3, and an opposed movable mould assembly 5 which is movable in a reciprocating manner by a ram or plunger 7 driven by a conventional pneumatic press 9 or other similar device. The plunger 7 is movable through an appropriate opening in a support member 11. The two mould assemblies are contained in a glass envelope 13 which defines a moulding chamber in which the atmospheric conditions can be controlled.

40 The mould assemblies 1 and 5 include (taken from the moulding area outwardly) glasslike carbon mould inserts 15 and 17, graphite cores 19 and 21 for supporting the inserts in an opposed relationship, supports 23 and 25 (which can be composed of graphite), sets of ceramic encased heaters 27 and 29 for supplying (by conduction) the heat required for the moulding operation, and thermocouple assemblies 31 and 33 which are thermally connected with the mould inserts for controlling the moulding temperatures.

50 The opposing surfaces 35 and 37 of the glasslike carbon mould inserts 15 and 17 are contoured according to the shape of the lens to be produced. These surfaces cooperate to form the opposite surfaces of the lens. They are finished, such as by grinding and polishing, to have a high surface accuracy and quality comparable to that of the intended lens.

60 In order to practice this embodiment of the invention effectively, it is necessary to maintain an oxygen-free atmosphere within the moulding chamber. Therefore, a set of

four input ports 41 for forming gas to be admitted to the chamber is provided. An entrance 43 is provided in the envelope 13 for admitting glass stock to the moulding area as described below, and a gas jet 45 surrounds the entrance 43 for releasing oxygen-free gas which is ignited to form a flame curtain to prevent the passage of oxygen into the chamber. In order to mould glass lenses with this apparatus, the end of a glass cane 47 is heated sufficiently to soften the glass, and the softened end is inserted through the entrance 43 and positioned between the opposing moulding surfaces of the glasslike carbon inserts.

80 A preferred method of moulding glass lenses in this apparatus involves the steps of preheating the glasslike carbon mould members, heat-softening a portion of glass (such as the end of a glass cane as explained above), placing the softened glass in the mould, compressing the mould until the glass conforms to the shape of the mould cavity, and opening the mould and removing the finished lens.

90 More specifically, one method of producing finished glass lenses in apparatus of the type shown in Figures 1 and 2 involves the steps of: adjusting the power to heaters 27 and 29 to preheat the opposite mould inserts 15 and 17 to raise the temperature of the mould to within the temperature range of 530°C—590°C (the preheating of the mould prevents thermal shock and the creation of glass deformities which would otherwise occur were there a significant temperature differential between the mould and the glass therein);

105 establishing a flow rate of five cubic feet per hour of a gas consisting of 95% nitrogen and 5% hydrogen into the moulding chamber through the ports 41 to prevent any oxidation within the chamber, and igniting gas released by the jet 45;

110 heat softening a $\frac{1}{4}$ " cane of optical crown glass to a temperature of 600°C—700°C, such as with a pair of opposing gas-air burners;

115 inserting the softened end of the cane through the entrance 43 and positioning it between the inserts 15 and 17;

applying a load of from 200 to 300 pounds on the mould assembly 5;

120 maintaining the load from 2 to 20 seconds;

removing the load, taking the cane with the lens attached thereto from the mould; and cracking the finished lens from the cane.

125 The foregoing method has been used to produce lenses having a diameter of 15.9 mm; a thickness of 2.00 mm; and a radius of curvature of 10.0 cm.

The apparatus of Figure 3 comprises a stationary upper mould assembly 101 fixed 130

in an upper mould assembly 105 and a lower mould assembly 103 which is vertically movable through a circular aperture 107 provided in a base plate 109. The upper mould assembly 105 and the base plate 109 are connected by a set of bolts 111 which extend through a set of tubes 113.

A moulding chamber is defined by a borosilicate glass envelope 115 which has a cylindrical shape and which encloses the moulding space located between the upper and lower mould assemblies. A port 117 (which can be closed by a valve which is not shown) is connected to the chamber defined by envelope 115 for exhausting gas from the chamber; a second port 119 is similarly connected to the chamber for admitting forming gas to the chamber; and a third port 121 is also connected to the chamber and serves as an exhaust for the forming gas, there being provided a check valve (not shown) for regulating the exhaust to control thereby the pressure of the forming gas in the chamber.

A bellows 123 is disposed beneath the lower mould assembly 103 and its interior is connected to the chamber defined by the envelope 115. The purpose of the bellows is to permit movement of the lower mould assembly 103 upwardly while maintaining control of the atmosphere in the chamber.

As will be seen in Figure 4, the upper mould assembly 101 has disposed on the lower face thereof a glasslike carbon mould member comprising an insert 125 which is configured to provide the proper shape of the part of the lens to be produced thereby. A similar mould member in the form of an insert 127 is disposed opposite to the insert 125 and is mounted on the upper face of the lower mould assembly 103. The opposing surfaces of the two glasslike carbon mould inserts cooperate to form the opposite faces of the lens to be produced by the mould. A ring-like element 129 is disposed around the insert 127 for adding the necessary thickness to the lens to be produced. The mould surfaces are finished to a high surface accuracy, and they are polished to a high surface quality comparable to that of the intended lens.

The lower mould assembly 103 is displaceable towards the upper mould assembly 101, and its path is accurately maintained by a pair of guide pins 131 which travel in appropriate inserts 133 extending into the lower mould assembly 103. The pins and inserts can advantageously be made of aluminium oxide.

A heating coil 134 is wrapped around the envelope 115 so as to surround the moulding area. When the coils are activated, the elements 125 and 127, as well as a pair of graphite supports 143 and 145 on which the respective elements 125 and 127 are moun-

ted, are heated by induction. Heat is transmitted by conduction from the supports 143 and 145, which act as heat reservoirs, to the elements 125 and 127.

The mould temperature is controlled by a pair of thermocouples 135 and 137, which are connected to the glasslike carbon mould members by means of appropriate leads 139 and 141 extending through the two mould assemblies, as shown in Figures 5A and 5B. In order to confine the heat to the moulding vicinity, pyrolytic insulators 147 and 149 are disposed on the sides of the graphite supports 143 and 145, opposite the glasslike mould inserts. The graphite conducts heat in the horizontal direction (with reference to the drawings) and is non-conductive in the vertical direction. The lower mould assembly 103 can be displaced by pneumatic, hydraulic, mechanical or any other appropriate means (not shown).

A preferred method of moulding glass lenses in the apparatus just described is begun by placing a preform or piece of glass 151 (see Figure 5A) in the lower mould insert 127. The chamber defined by the envelope 115 is evacuated to a low pressure; the graphite supports 143 and 145, as well as the glasslike carbon mould inserts 125 and 127, are outgassed by the induction heating of the mould during the evacuation of the chamber to remove gases absorbed by the carbon; forming gas (preferably consisting of 95% nitrogen and 5% hydrogen and maintained under a slight over-pressure) is introduced into the chamber; and the mould members are heated further to increase the plasticity of the glass. A load is added to the lower mould assembly, and the temperature of the mould is reduced to bring the temperature of the glass to below the glass transformation point. By keeping the temperature of the glass and of the mould substantially equal while maintaining a load on the mould, distortion of the glass is prevented as the temperature is reduced below the glass transformation point. The load is removed, and the moulds are further cooled to prevent oxidation of the moulds and graphite; the apparatus is opened; and the finished lens is taken from the mould. If a device such as a glove box surrounds the moulding apparatus, the lens can be removed as soon as the load is removed.

This method has been used to produce very precisely finished lenses having a power of within 2 Newton's rings and an irregularity of within one Newton's ring.

The preferred specific conditions under which the process can be practiced are as follows:

after placing a dense barium crown optical glass in the lower mould insert 127, the chamber defined by the envelope 115 and

the bellows assembly 123 is evacuated to a pressure of approximately 100 microns;

the outgassing operation is accomplished by induction heating the mould to between 200°C and 300°C during the evacuation of the chamber;

the port 117 is closed and a forming gas of 95% nitrogen and 5% hydrogen is introduced into the chamber through the port 119 and maintained under a slight overpressure;

the power to the induction coils 134 is adjusted to raise the mould temperature to between 700°C and 800°C (which is in the region of the softening point of the glass);

the upper mould assembly is brought into close proximity with the softened glass resting on the lower mould assembly, and the preceding temperature is maintained for one to five minutes (the glass is heated by conduction from the mould insert 127 and by radiation from the mould insert 125);

a load of from 10 pounds to 200 pounds is applied to the lower mould assembly 103 and held for one minute to bring the glass into intimate contact with the mould cavity-defining surfaces, as shown in Figure 5B;

the induction heating of the mould members is terminated and the mould portions are allowed to cool until a temperature of 500°—600°C, more preferably 550°—600°C, is reached (this being below the 622°C transformation point of the glass);

the load on the lower mould assembly 103 is removed and the temperature of the mould and glass is allowed to cool to 300°C to prevent oxidation of the glasslike carbon mould inserts and of the graphite supports; and

the mould is opened and the finished lens is removed from the mould.

The preceding method has produced very high quality lenses, the lenses in one case having radii of curvature of 11 mm. on one side and 86 mm. on the other side. Lenses produced by the foregoing method have been found to be essentially strain free so that further annealing was unnecessary.

The two forms of apparatus described with reference to Figures 1—2 and 3—5B are not essential for carrying out the present invention, and other types of moulding apparatus may be more suitable for different situations and conditions. All the foregoing temperatures, pressures and time periods which have been quoted will of course vary depending upon the nature of the lens and of the glass.

One suitable type of glass is an optical barium crown glass having a softening temperature of from 700° to 800°C and an annealing temperature of from 600° to 700°C.

As indicated earlier, the present invention has been found to produce image forming lenses having surfaces of a high quality and

a high accuracy. The method of the invention is effective in the production of lenses having spherical and aspherical surfaces.

Lenses produced by the moulding method of the present invention have been found to be superior to ground and polished lenses in a significant respect. When lenses are ground and polished, there is a flow of glass at the surface of the lenses which results from the action of the grinding tools and from the heat generated thereby. The glass tends to flow into the minute pits which exist near the glass surface, and to trap air in the pits in the form of air pockets or bubbles. These air pockets detract from the quality of the lens because they increase the amount of light which it scatters. Moulding does not entrap air in the lens, and therefore moulded lenses do not exhibit the light scattering disadvantage.

WHAT WE CLAIM IS:—

1. A method of moulding glass into an optical lens having a predetermined shape, wherein a portion of glass is placed between mould members having open and closed positions, the mould members including glass-contacting surfaces formed of glasslike carbon (as hereinbefore defined) having a high surface quality and a high surface accuracy (as hereinbefore defined) and being shaped to define in the closed position of the mould members a cavity configured to produce a lens of said predetermined shape, the mould members are moved to their closed position until the glass in the mould cavity conforms to the shape of the cavity under the effect of heat and the application of pressure in a non-oxidizing atmosphere, the mould members are moved to their open positions, and the moulded lens is removed.

2. A method as claimed in Claim 1, wherein the mould members are preheated and the glass is softened before being placed between the mould members.

3. A method as claimed in Claim 1 or 2, wherein the mould members are preheated to a temperature of from 530°C. to 590°C., and wherein the glass is optical crown glass and is heat-softened to a temperature of from 600°C. to 700°C.

4. A method as claimed in Claim 1, 2 or 3, wherein the nonoxidizing atmosphere consists of 95% nitrogen and 5% hydrogen.

5. A method as claimed in any one of the preceding claims, wherein after the mould members have been moved to their closed positions, a load of from 200 to 300 pounds is applied for a period of from 2 to 20 seconds.

6. A method as claimed in Claim 1, wherein the mould members are heated to soften the glass, the mould members are moved to their closed position to place the glass-contacting surfaces in contact with the



the bellows assembly 123 is evacuated to a pressure of approximately 100 microns;

the outgassing operation is accomplished by induction heating the mould to between
5 200°C and 300°C during the evacuation of the chamber;

the port 117 is closed and a forming gas of 95% nitrogen and 5% hydrogen is introduced into the chamber through the port 119
10 and maintained under a slight overpressure;

the power to the induction coils 134 is adjusted to raise the mould temperature to between 700°C and 800°C (which is in the region of the softening point of the glass);

the upper mould assembly is brought into close proximity with the softened glass resting on the lower mould assembly, and the preceding temperature is maintained for one to five minutes (the glass is heated by conduction from the mould insert 127 and by radiation from the mould insert 125);

a load of from 10 pounds to 200 pounds is applied to the lower mould assembly 103 and held for one minute to bring the glass into intimate contact with the mould cavity-defining surfaces, as shown in Figure 5B;

the induction heating of the mould members is terminated and the mould portions are allowed to cool until a temperature of 500°—600°C, more preferably 550°—600°C, is reached (this being below the 622°C transformation point of the glass);

the load on the lower mould assembly 103 is removed and the temperature of the mould and glass is allowed to cool to 300°C to prevent oxidation of the glasslike carbon mould inserts and of the graphite supports; and

the mould is opened and the finished lens is removed from the mould.

The preceding method has produced very high quality lenses, the lenses in one case having radii of curvature of 11 mm. on one side and 86 mm. on the other side. Lenses
45 produced by the foregoing method have been found to be essentially strain free so that further annealing was unnecessary.

The two forms of apparatus described with reference to Figures 1—2 and 3—5B are not essential for carrying out the present invention, and other types of moulding apparatus may be more suitable for different situations and conditions. All the foregoing temperatures, pressures and time periods
55 which have been quoted will of course vary depending upon the nature of the lens and of the glass.

One suitable type of glass is an optical barium crown glass having a softening temperature of from 700° to 800°C and an annealing temperature of from 600° to 700°C.

As indicated earlier, the present invention has been found to produce image forming
65 lenses having surfaces of a high quality and

a high accuracy. The method of the invention is effective in the production of lenses having spherical and aspherical surfaces.

Lenses produced by the moulding method of the present invention have been found to be superior to ground and polished lenses in a significant respect. When lenses are ground and polished, there is a flow of glass at the surface of the lenses which results from the action of the grinding tools and from the heat generated thereby. The glass tends to flow into the minute pits which exist near the glass surface, and to trap air in the pits in the form of air pockets or bubbles. These air pockets detract from the quality of the lens because they increase the amount of light which it scatters. Moulding does not entrap air in the lens, and therefore moulded lenses do not exhibit the light scattering disadvantage.

WHAT WE CLAIM IS:—

1. A method of moulding glass into an optical lens having a predetermined shape, wherein a portion of glass is placed between mould members having open and closed positions, the mould members including glass-contacting surfaces formed of glasslike carbon (as hereinbefore defined) having a high surface quality and a high surface accuracy (as hereinbefore defined) and being shaped to define in the closed position of the mould members a cavity configured to produce a lens of said predetermined shape, the mould members are moved to their closed position until the glass in the mould cavity conforms to the shape of the cavity under the effect of heat and the application of pressure in a non-oxidizing atmosphere, the mould members are moved to their open positions, and the moulded lens is removed.

2. A method as claimed in Claim 1, wherein the mould members are preheated and the glass is softened before being placed between the mould members.

3. A method as claimed in Claim 1 or 2, wherein the mould members are preheated to a temperature of from 530°C. to 590°C., and wherein the glass is optical crown glass and is heat-softened to a temperature of from 600°C. to 700°C.

4. A method as claimed in Claim 1, 2 or 3, wherein the nonoxidizing atmosphere consists of 95% nitrogen and 5% hydrogen.

5. A method as claimed in any one of the preceding claims, wherein after the mould members have been moved to their closed positions, a load of from 200 to 300 pounds is applied for a period of from 2 to 20 seconds.

6. A method as claimed in Claim 1, wherein the mould members are heated to soften the glass, the mould members are moved to their closed position to place the glass-contacting surfaces in contact with the



softened glass, sufficient force is applied to the mould members to bring the glass into intimate contact with the surfaces, the temperature of the mould members is reduced, and force is removed from the mould members, and the mould members are cooled further before being moved to their open position.

7. A method as claimed in Claim 6, wherein oxygen is substantially removed from the vicinity of the mould members and forming gas is placed thereabout to prevent oxidation before the mould members are heated to soften the glass.

8. A method as claimed in Claim 7, wherein the forming gas consists of 95% nitrogen and 5% hydrogen and is maintained under a slight overpressure.

9. A method as claimed in any one of Claims 6 to 8, wherein the glass is an optical barium crown glass having a softening temperature of from 700 to 800°C. and an annealing temperature of from 600 to 700°C.

10. A method as claimed in Claim 9, wherein the mould members are located in a hermetically sealed chamber, the chamber is evacuated after the glass has been placed on one of the mould surfaces, and the mould members are outgassed by being heated to a temperature of 200 to 300°C.

11. A method as claimed in Claim 10, wherein the mould members are then heated to a temperature of from 700 to 800°C., the mould members are moved into their closed position and held in close proximity with the glass for 1 to 5 minutes, and a load of from 10 to 200 pounds is applied to the mould members and maintained for one minute.

12. A method as claimed in Claim 11, wherein the mould members are then cooled until the glass temperature is below the transformation point of the glass.

13. A method as claimed in Claim 12, wherein the mould members are cooled to between 500 and 600°C., and after the load has been removed from the mould members, their temperature is reduced to 300°C.

14. A method as claimed in any one of the preceding claims, wherein the mould members are supported on graphite supports.

15. A method of moulding glass into an optical lens having a predetermined shape, substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

16. A method of moulding glass into an optical lens having a predetermined shape, substantially as hereinbefore described with reference to Figures 3, 4, 5A and 5B of the accompanying drawings.

17. A lens which has been moulded by a method as claimed in Claim 1.

18. A lens which has been moulded by

a method as claimed in any one of Claims 2 to 5.

19. A lens which has been moulded by a method as claimed in any one of Claims 6 to 14.

20. Apparatus for moulding glass into an optical lens having a predetermined shape, comprising mould members movable between open and closed positions and having glass-contacting surfaces formed of glass-like carbon (as hereinbefore defined) defining, when the mould members are in their closed position, a mould cavity configured to produce a lens of said predetermined shape, the glass-contacting surfaces having a high surface quality and a high surface accuracy (as hereinbefore defined) comparable with the surface quality and surface accuracy required of said lens, and means for establishing a non-oxidizing atmosphere around the mould members.

21. Apparatus as claimed in Claim 20, also comprising heating means for preheating the mould members, heating means for heat-softening an optical glass, and means for placing the heat-softened glass between the mould members.

22. Apparatus as claimed in Claim 20, comprising heating means for heating the mould members above the softening point of optical glass to be used in the apparatus, means for controlling the temperature of the mould members, a chamber within which the mould members are movable to the closed position and within which the pressure and content of the atmosphere can be controlled, means for controlling the oxygen content of the atmosphere within the chamber, and means for urging the mould members together under a predetermined load.

23. Apparatus as claimed in Claim 22, wherein the means for controlling the oxygen content within the chamber comprises means for evacuating the chamber, means for introducing forming gas to the chamber, and means for controlling the pressure of the gas.

24. Apparatus as claimed in any one of Claims 20 to 23, wherein the mould members are supported on graphite support blocks.

25. Apparatus for moulding glass into an optical lens having a predetermined shape, substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

26. Apparatus for moulding glass into an optical lens having a predetermined shape, substantially as hereinbefore described with reference to Figures 3, 4, 5A and 5B of the accompanying drawings.

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