

- 1543 954
- (21) Application No. 36424/76 (22) Filed 2 Sept. 1976 (19)
 (31) Convention Application Nos. 609 328 (32) Filed 2 Sept. 1975 in
 609 329
 (33) United States of America (US)
 (44) Complete Specification published 11 April 1979
 (51) INT. CL.³ C03B 11/00
 (52) Index at acceptance
 CIM 450 KH



(72) Inventors GERALD E. BLAIR, JOHN J. MEYERS,
 JOHN H. SHAFER and FRANK T. J. SMITH

(54) METHOD OF MAKING OPTICAL ELEMENTS AND MOULDS FOR USE
 THEREIN

(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 a method of
 making optical elements and moulds for use
 therein.

The surface of an optical element, such as a
 lens element, should be free from defects,
 such as scratches, pits, voids and "orange
 peel", and should have exactly the desired
 form. The 'surface accuracy' is usually
 determined by interferometric comparison
 with a test plate gauge, the number and
 regularity of Newton's rings generated, for
 light of a specific colour, being noted. The
 surface accuracy of an element is often
 referred to as its 'fit', and is expressed in
 terms of its 'power' (the maximum number of
 Newton's rings appearing across a radius of
 the lens) and its 'irregularity' (the difference
 between that number and the number of
 rings counted across a radius at right angles
 to the radius used in assessing the 'power').
 The lower the values of the power and
 irregularity, the better the lens. For instance,
 the surface accuracy of a lens to be used in
 photographic apparatus is usually considered
 high when it has a power of less than six
 rings and an irregularity of less than three
 rings.

The manufacture of finished glass optical
 elements has conventionally required a series
 of steps, including preliminary moulding,
 grinding, polishing and centering. Each of
 these steps is a separate operation requiring
 complex and expensive apparatus and skilled
 operators. When the design requires a non-
 spherical surface, it may be necessary for each
 element to be individually ground and
 polished.

Plastics materials have several advantages
 over glass in lens manufacture; notably they
 are light, shatterproof, and mouldable at
 relatively low temperatures. However, the
 plastics which are practical for use as lens
 materials, such as polystyrene, polycyclohexyl
 methacrylate, and polymethyl methacrylate,
 are relatively soft and scratch easily. More-
 over, the latter plastic is frequently hazy and
 sometimes yellowish. Also, plastics usually
 soften within the range of 60° to 80°C. and
 their indices of refraction may change in time.
 Most plastics absorb water and are subject to
 dimensional change due to cold flow under
 pressure and to a thermal expansion coeffi-
 cient which is almost ten times that of glass.
 This high thermal expansion causes cor-
 responding changes in refractive index which
 may severely affect the optical performance
 of the lens.

Methods and apparatus for moulding in
 glasslike carbon moulds glass lenses that
 require no subsequent finishing operations
 are described in U.S. Patents Nos. 3,833,347,
 3,844,755 and 3,900,328.

Glasslike carbon as used in these methods
 is subject to oxidation, is structurally weak,
 thus being readily scratched, has a low
 modulus of elasticity, has low fracture and
 impact strengths, and has low thermal con-
 ductivity.

According to the present invention, there
 is provided a method of making an optical
 element which comprises pressing heat-
 softened glass in a non-oxidizing environment
 against an optically smooth mould surface
 formed of silicon carbide, silicon nitride or a
 mixture of silicon carbide and carbon and
 maintaining pressure on the glass until it has
 cooled to below its transition temperature.

Also provided in accordance with the
 invention are moulds for use in carrying out
 said method. The mould materials used for
 the present invention exhibit minimal chemi-
 cal activity to glass at high temperatures, are
 impermeable to gases, water vapour and
 liquids and are not permanently adhered to

by heat-softened glass. Relative to glasslike carbon, each of these materials is more resistant to oxidation, and has higher fracture and impact strengths at high temperatures, greater physical hardness (being therefore less subject to scratching) and higher thermal conductivity (thereby allowing for more rapid thermal cycling). The non-oxidizing environment in which the method of the invention is carried out is preferably a nitrogen atmosphere.

The present invention provides a method for moulding glass optical elements of high surface quality and accuracy, which are suitable, for instance, for use in photographic apparatus. A layer providing a moulding surface used in the method of the invention has to be sufficiently thick for the surface characteristics of the mould to be determined exclusively by that surface, there being no interaction between the substrate carrying the mould surface and the moulded glass. Preferably, the layer is at least 10 microns thick.

Silicon carbide or silicon nitride useful in the practice of the invention can be prepared by any of several methods. One method is by hot-pressing to produce a fine-grained silicon carbide or silicon nitride. A second method comprises depositing silicon carbide or silicon nitride, either as a solid body or as a layer on a suitable substrate, by the use of a "sputtering" technique in which ions are ejected from a source body by action of ionic bombardment, and are redeposited to form a moulding surface. In a third method, silicon carbide or silicon nitride is prepared by chemical vapour deposition, again either as a solid piece or as a layer on a suitable substrate. Silicon carbide or silicon nitride produced by the second and third methods possesses the advantageous properties of lacking internal voids and having the capability of being polished to a continuous, highly specular surface.

A mixture of silicon carbide and carbon useful in the practice of the invention can be prepared either by a sputtering technique or by chemical vapour deposition, either as a solid piece or as a layer on a suitable substrate. A mixture of silicon carbide and carbon produced by either of these methods possesses the advantageous properties of lacking internal voids and having the capability of being polished to a continuous, highly specular surface. Vapour deposition is preferred, because it provides ready and accurate control of the composition of the deposited mixture. A description of one method for producing a mixture of silicon carbide and carbon may be found in Kaae & Gulden, "Structure and Mechanical Properties of Codeposited Pyrolytic C-SiC Alloys", Journal of the American Ceramic Society, pages 605-609, 54, No. 12, 1971.

Several techniques may be used to produce a moulding surface useful in the practice of the invention. If the material is in a solid piece, the piece can be ground and polished to the desired shape and finish. The solid piece is preferably roughly shaped during its formation, to minimize the amount of grinding required. A second technique involves generating, grinding, and polishing the mould directly from a deposit of the mould material. This deposit must be thick enough to provide a sufficient base for support and mounting, allowing for material to be cut away in forming the desired curve. Another technique involves forming a relatively thin deposit of the mould material on a precurved substrate of a material such as graphite, molybdenum, or hot pressed silicon carbide or silicon nitride. The deposit must be of such thickness that even after grinding and polishing to the desired specifications, the moulding surface characteristics are exclusively attributable to the deposited layer. A fourth technique for forming a suitable moulding surface involves the use of an inverse mould form surface as a base for deposit of the mould material. In this technique, a parting or release agent is first applied to the inverse mould form, followed by the deposition of a relatively thick layer of the particular material. The resulting mould surface separates at the parting layer from the inverse mould form and can be used with little or no surface corrections. Again, the layer must be sufficiently thick so that the moulding characteristics are exclusively attributable to the deposited layer of material. The silicon carbide or silicon nitride moulds so produced are preferably installed as inserts in sturdy support members for strength and durability.

During the grinding and polishing of a mould for use in the invention, the mould cavities may be configured to yield a glass element of a predetermined shape with a mould mounting shoulder and the ridges and grooves associated with mounting seats. Provision may have to be made for dimensional changes which occur during and after the moulding process. In this way, a moulded element requiring no subsequent grinding and polishing, and so ready for final assembly may be made.

In the preferred embodiments of the invention described below, reference is made to the accompanying drawings, in which:—

Fig. 1 is a partially cut away perspective view of a moulding apparatus for producing glass elements according to the invention;

Fig. 2 is a detailed view of a mould employed in the moulding apparatus shown in Fig. 1; and

Figs. 3A and 3B are partial cross-sectional views, taken through the line 3—3 in Fig. 2,

at different stages of the operation of the moulding apparatus of Fig. 1.

As shown in Fig. 1, a moulding apparatus comprises an upper mould assembly 1 and a lower mould assembly 3. The upper mould assembly 1 is fixed in an upper mount 5 whereas the lower mould assembly 3 is vertically movable through a circular aperture 7 provided in a base plate 9. The upper mount 5 and base plate 9 are connected by a set of bolts 11 which extend through a set of tubes 13. A moulding chamber is defined by a cylindrical borosilicate glass (such as 'Pyrex': trade mark) envelope 15 which encloses the moulding space located between the upper and lower mould assemblies. A port 17 (which can be closed by a valve which is not shown) is connected to the moulding chamber for exhausting gas from the chamber; a second port 19 is provided for admitting a controlled atmosphere to the moulding chamber; a third port 21 serves as an exhaust for the controlled atmosphere, there being a check valve (not shown) for regulating the exhaust, thereby controlling the pressure of gas in the moulding chamber. A bellows 23 is disposed beneath the lower mould assembly 3, its interior communicating with the moulding chamber defined by envelope 15. The bellows 23 allows the lower mould assembly 3 to be moved up or down whilst maintaining atmosphere control in the moulding chamber.

Referring to Fig. 2, the upper mould assembly 1 carries at its lower face a mould member comprising an insert 25, formed of silicon carbide, silicon carbide and carbon or silicon nitride, having surface contour and finish needed for producing a lens of the desired quality. A second mould member in the form of an insert 27 is disposed opposite to the insert 25 and is mounted on the upper face of the lower mould assembly 3. The opposing surfaces of the two mould inserts 25 and 27 cooperate to form the opposite faces of the lens to be produced by the mould. A ring 29, preferably made of the same material as the inserts 25 and 27, is disposed around insert 27 to determine the thickness to the lens to be moulded. Ring 29 may be eliminated for open-die moulding. The dimensions of inserts 25 and 27 and the ring 29 may have to be chosen to allow for dimensional changes which may occur during and after the moulding process. The lower mould assembly 3 is displaceable towards upper mould assembly 1, by means (not shown) and its path is accurately defined by a pair of guide pins 31 which travel in appropriate cavities 33 extending into the lower mould assembly 3.

A heating coil 34 is wrapped around envelope 15 so as to surround the moulding area. When the coil is activated, the ring 29 and inserts 25 and 27, as well as a pair of

supports 43 and 45 on which the respective inserts 25 and 27 are mounted, are heated by induction. Heat is transmitted by conduction from the supports 43 and 45, which act as heat reservoirs, to the inserts 25 and 27.

The mould temperature is controlled by a pair of thermocouples, the associated instruments being shown as 35 and 37. The hot junctions are in contact with the inserts 25 and 27, the leads 39 and 41 extending through the two mould assemblies, as shown in Figs. 3A and 3B. In order to confine the generated heat to the moulding vicinity, a pair of cylindrical pyrolytic graphite insulators 47 and 29 are disposed on the ends of the supports 43 and 45, opposite the inserts 25 and 27. These insulators are made so as to conduct heat more readily in a radial than an axial direction.

According to a preferred method of moulding optical elements by this invention, a quantity of glass 51 is placed within the moulding chamber. It may be set in contact with insert 27, as shown in Fig. 3A or provision may be made to hold the glass out of contact with inserts 25 and 27 until heated. The glass must be shaped to fit within the moulding chamber but need not be preformed to a different volume and shape for different lens designs, although preforming is preferable. Preferably, the surface of the glass slug is fire or machine polished to a high quality. The lower mould assembly 3 is then raised to bring the glass 51, ring 29 and insert 27 into the moulding chamber and into proximity with insert 25. The atmosphere within the moulding chamber is then evacuated through port 17. Simultaneously, heat is introduced into the moulding chamber by means of coil 34 to outgas the moulding chamber and its contents. The desired controlled atmosphere, preferably nitrogen, is introduced into the moulding chamber through port 19, with pressure control by port 21. Heating coil 34 is again actuated causing continued heating of the supports 43 and 45, ring 29, inserts 25 and 27 and the glass 51 in the moulding chamber until the desired moulding temperature is reached. The temperature of the inserts 25 and 27 is monitored by thermocouples as shown, by optical pyrometry equipment or by other suitable means. When the desired temperature has been attained and stabilized, the glass 51, ring 29 and inserts 25 and 27 are at similar temperatures. A force is now applied to lower mould assembly 3, bringing the ring 29 into contact with the insert 25, thereby forming a moulding cavity. After a suitable moulding time, the temperature of the mould is reduced gradually to bring the temperature below the glass transformation point while still maintaining a load of the glass, to minimize distortion of glass as the temperature is reduced. After the glass has solidified, the

load is removed from the lower mould assembly 3; the mould is further cooled to prevent oxidation; the apparatus is opened; and the finished lens taken out of the mould.

- 5 In an alternative method of the invention, a mould as specified for the present is used in apparatus as described in U.S. Patent No. 3,900,328 (United Kingdom Specification 1,367,335). With such apparatus, a portion of
10 glass is heat-softened before being introduced the mould cavity between the moulding surfaces, the subsequent pressing procedure being similar to that described above.

- 15 Mould surfaces as used for the present invention may also be employed in apparatus as described in U.S. Patent No. 3,844,755 (United Kingdom Specification 1,441,029). In using this apparatus, an unheated portion of glass is placed in a transfer chamber which
20 is preferably lined with silicon carbide, silicon nitride or mixture of silicon carbide and carbon; the mould members, transfer chamber and glass are heated to soften the glass and the heated glass is forced from the
25 transfer chamber through sprues into mould cavities defined by the moulding surface. The remainder of the manufacturing process is similar to that described above.

- 30 The following Examples illustrate the invention.

Example 1

- Using the apparatus shown in the drawings, with the lower mould assembly 3 in its
35 downward position, a portion of extra dense flint optical glass was placed on insert 27 formed of silicon carbide by a chemical vapour deposition technique. The lower mould assembly 3 was moved up into the
40 moulding chamber close to upper mould assembly insert 25 which was also formed of silicon carbide. The moulding chamber was then evacuated by means of port 17 to approximately 200 microns mercury pressure
45 and simultaneously, the surfaces of the glass ring 29 and inserts 25 and 27 were outgassed at a temperature between 400°F and 570°F by means of heating coil 34. The port 17 was
50 then closed and a controlled atmosphere of nitrogen gas introduced into the moulding chamber through port 19, with a slight over pressure maintained by means of port 21. Power to coil 34 was adjusted to raise the
55 temperature within the moulding chamber until the glass softened sufficiently to mould and the temperature was maintained for a period of about 1.5 minutes (a temperature of about 1050°F for extra dense flint optical
60 glass is sufficient, but the necessary temperature will vary depending on the nature of the glass being moulded). A force was then applied to the lower mould assembly 3, thereby pressing the heat-softened glass within the moulding chamber between ring
65 29 and inserts 25 and 27 as shown in Fig. 3B.

The force applied provided a pressure of approximately 130 pounds per square inch and was maintained for about 10 seconds. Heating of the mould members was terminated during this period, so that the upward
70 force was maintained on the lower mould assembly 3 until the glass had cooled to below its transformation temperature. The mould chamber was allowed to cool to about 400°F, before opening for removal of the
75 moulded glass element minimize the possibility of oxidation of the ring 29, inserts 25 and 27 and supports 43 and 45.

Example II

A concave lens was moulded using the apparatus and technique described in Example I, except that the inserts 25 and 27 were formed by coating a substrate in the form of a hollow graphite ball having a
80 diameter of 0.850 inches and a wall thickness of 2 mm with a 0.5 mm thick layer of a material comprising a mixture of silicon carbide and carbon, the silicon carbide being approximately 11% by weight; cutting the
85 coated substrate in half, and performing the polishing necessary to secure a specular surface having high surface quality and high surface accuracy.

WHAT WE CLAIM IS:—

1. A method of making an optical element which comprises pressing heat-softened glass in a non-oxidizing environment against an optically smooth mould
100 surface formed of silicon carbide or silicon nitride and maintaining pressure on the glass until it has cooled to below its transition temperature.
2. A method of making an optical
105 element which comprises pressing heat-softened glass in a non-oxidizing environment against an optically smooth mould surface formed of a mixture of silicon carbide and carbon and maintaining pressure on the
110 glass until it has cooled to below its transition temperature.
3. A method according to Claim 1 wherein the heat-softened glass is pressed between a plurality of mould surfaces which
115 define a mould cavity, each mould surface being formed of silicon carbide or silicon nitride.
4. A method according to Claim 2 wherein the heat-softened glass is pressed
120 between a plurality of mould surfaces which define a mould cavity, each mould surface being formed of a mixture of silicon carbide and carbon.
5. A method according to Claim 1 substantially as described in Example 1 herein.
6. A method according to Claim 2 substantially as described in Example 2 herein.
7. An optical element made by a method
125 according to any of Claims 1, 3 and 5.

load is removed from the lower mould assembly 3; the mould is further cooled to prevent oxidation; the apparatus is opened; and the finished lens taken out of the mould.

- 5 In an alternative method of the invention, a mould as specified for the present is used in apparatus as described in U.S. Patent No. 3,900,328 (United Kingdom Specification 1,367,335). With such apparatus, a portion of
10 glass is heat-softened before being introduced the mould cavity between the moulding surfaces, the subsequent pressing procedure being similar to that described above.

- 15 Mould surfaces as used for the present invention may also be employed in apparatus as described in U.S. Patent No. 3,844,755 (United Kingdom Specification 1,441,029). In using this apparatus, an unheated portion of glass is placed in a transfer chamber which
20 is preferably lined with silicon carbide, silicon nitride or mixture of silicon carbide and carbon; the mould members, transfer chamber and glass are heated to soften the glass and the heated glass is forced from the transfer chamber through sprues into mould
25 cavities defined by the moulding surface. The remainder of the manufacturing process is similar to that described above.

- 30 The following Examples illustrate the invention.

Example 1

- Using the apparatus shown in the drawings, with the lower mould assembly 3 in its
35 downward position, a portion of extra dense flint optical glass was placed on insert 27 formed of silicon carbide by a chemical vapour deposition technique. The lower mould assembly 3 was moved up into the
40 moulding chamber close to upper mould assembly insert 25 which was also formed of silicon carbide. The moulding chamber was then evacuated by means of port 17 to approximately 200 microns mercury pressure
45 and simultaneously, the surfaces of the glass ring 29 and inserts 25 and 27 were outgassed at a temperature between 400°F and 570°F by means of heating coil 34. The port 17 was
50 then closed and a controlled atmosphere of nitrogen gas introduced into the moulding chamber through port 19, with a slight over pressure maintained by means of port 21. Power to coil 34 was adjusted to raise the
55 temperature within the moulding chamber until the glass softened sufficiently to mould and the temperature was maintained for a period of about 1.5 minutes (a temperature of about 1050°F for extra dense flint optical glass is sufficient, but the necessary temperature will vary depending on the nature of the
60 glass being moulded). A force was then applied to the lower mould assembly 3, thereby pressing the heat-softened glass within the moulding chamber between ring 29 and inserts 25 and 27 as shown in Fig. 3B.

The force applied provided a pressure of approximately 130 pounds per square inch and was maintained for about 10 seconds. Heating of the mould members was terminated during this period, so that the upward
70 force was maintained on the lower mould assembly 3 until the glass had cooled to below its transformation temperature. The mould chamber was allowed to cool to about 400°F, before opening for removal of the
75 moulded glass element minimize the possibility of oxidation of the ring 29, inserts 25 and 27 and supports 43 and 45.

Example II

A concave lens was moulded using the apparatus and technique described in Example I, except that the inserts 25 and 27 were formed by coating a substrate in the form of a hollow graphite ball having a
80 diameter of 0.850 inches and a wall thickness of 2 mm with a 0.5 mm thick layer of a material comprising a mixture of silicon carbide and carbon, the silicon carbide being approximately 11% by weight; cutting the
85 coated substrate in half, and performing the polishing necessary to secure a specular surface having high surface quality and high surface accuracy.

WHAT WE CLAIM IS:—

1. A method of making an optical element which comprises pressing heat-softened glass in a non-oxidizing environment against an optically smooth mould
100 surface formed of silicon carbide or silicon nitride and maintaining pressure on the glass until it has cooled to below its transition temperature.
2. A method of making an optical
105 element which comprises pressing heat-softened glass in a non-oxidizing environment against an optically smooth mould surface formed of a mixture of silicon carbide and carbon and maintaining pressure on the
110 glass until it has cooled to below its transition temperature.
3. A method according to Claim 1 wherein the heat-softened glass is pressed between a plurality of mould surfaces which
115 define a mould cavity, each mould surface being formed of silicon carbide or silicon nitride.
4. A method according to Claim 2 wherein the heat-softened glass is pressed
120 between a plurality of mould surfaces which define a mould cavity, each mould surface being formed of a mixture of silicon carbide and carbon.
5. A method according to Claim 1 substantially as described in Example 1 herein.
6. A method according to Claim 2 substantially as described in Example 2 herein.
7. An optical element made by a method according to any of Claims 1, 3 and 5.



* C L M S *

8. An optical element made by a method according to any of Claims 2, 4 and 6. surface which surface is formed of a mixture of silicon carbide and carbon.
9. A mould having an optically smooth surface which surface is formed of silicon carbide or silicon nitride. L. A. TRANGMAR, B.Sc., C.P.A.,
Agent for the Applicants.
10. A mould having an optically smooth

Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1979.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY,
from which copies may be obtained.

