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(54) **Title**: Manufacturing method

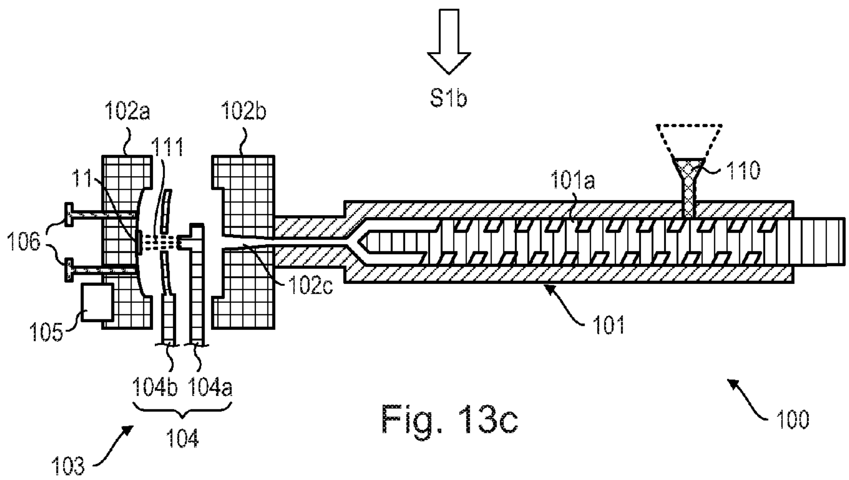

Fig. 13c

(57) **Abstract**: Manufacturing method A method of manufacturing a moulded part (10) with one or more integral electronic components (10a). The method includes forming one or more layers (11) in a mould of a moulding apparatus, the one or more layers including the one or more electronic components, and introducing material into the mould to form the moulded part with the one or more integral electronic components. (Figure 1)

WO 2014/091197 A1

Manufacturing method

Field of the invention

The present invention relates, amongst other things, to a manufacturing method and, in particular, to a method of manufacturing a moulded part with one or more integral electronic components.

Background

Electronic products are commonly manufactured by combining several separately-made components. For example, this may involve assembling components such as printed circuit board assemblies, batteries, and injection-moulded plastic cases.

The manufacture of electronic components, particularly silicon-based electronic components, is well understood. The moulding of plastic parts is also well understood.

Some effort has also been directed at bringing together certain aspects of these two manufacturing technologies.

An example of this is described in TEH et al. 'Embedding of electronics within thermoplastic polymers using injection moulding technique', in: Electronics Manufacturing Technology Symposium, 26th IEEE/CPMT International, 2000, p. 10-18. This document describes electronic sub-systems simultaneously packaged within an automotive structural thermoplastic component during an injection moulding process.

Another example is described in HOEBER et al. 'Electrical functionalization of thermoplastic materials by Aerosol Jet Printing', in: Electronics Packaging Technology Conference (EPTC), 2011 IEEE 13th, p. 813-818. This document describes aerosol-jet-printing to apply circuit tracks on three dimensional thermoplastic circuit carriers.

Summary

According to a first aspect of the present invention, there is provided a method of manufacturing a moulded part with one or more integral electronic components. The method includes forming one or more layers in a mould of a moulding apparatus, the one or more layers including the one or more electronic components, and introducing material into the mould to form the moulded part with the one or more integral electronic components.

Thus, moulded parts with integral electronic components can be efficiently manufactured, for example without requiring separate processes for manufacturing the electronic components, for manufacturing the moulded parts and for assembling them.

The method may include injecting the material into the mould to form an injection-moulded part with the one or more integral electronic components. In other words, the method may involve an injection-moulding process.

The method may include forming at least one of the one or more layers directly on the mould. The method may include forming a layer on the mould to enable the part to be released from the mould.

The method may include forming at least one of the one or more layers on a curved surface. Thus, moulded parts with electronic components (e.g. electroluminescent devices) over curved surfaces can be manufactured.

The method may include forming at least one of the one or more layers by spray deposition. Herein, “spray deposition” is intended to cover processes for depositing material in which the material is atomized to form a spray. The material may be atomized, for example, by means of an airbrush. The material to be atomized may be in a solution.

The method may comprise positioning a mask over the mould before forming at least one of the one or more layers. The mould and the mask may have corresponding surfaces. Thus, the size, shape and position of layers can be precisely controlled, even when, for example, they are formed on curved surfaces.

The method may include heating at least one of the one or more layers before forming a next one of the one or more layers or before introducing the material into the mould. In this way, the layers can be dried and/or cured. The method may include heating the mould to heat at least one of the one or more layers.

The method may include forming the one or more layers with respective predetermined sizes, shapes and positions. Thus, the properties of the one or more electronic components can be controlled, for example by electrically connecting or isolating layers from other layers.

The method may include, after forming the moulded part, forming a further moulded part with at least one different integral electronic component in the same mould.

According to a second aspect of the present invention, there is provided apparatus for manufacturing a moulded part with one or more integral electronic components. The apparatus is adapted to form one or more layers in a mould, the one or more layers including the one or more electronic components. The apparatus is adapted to introduce material into the mould to form the moulded part with the one or more integral electronic components.

The apparatus may include one or more sections for forming respective ones of the one or more layers. The one or more sections may be moveable relative to the mould. The one or more sections may be formed in the body of the mould.

According to a third aspect of the present invention, there is provided a moulded part with one or more integral electronic components. The moulded part includes moulded material and one or more layers including the one or more electronic components. At least one of the one or more layers is bonded to the moulded material. The part is obtainable by the method.

Thus, a durable part with electronic capabilities can be provided.

The one or more layers may be bonded to the moulded material by, for example, interdiffusion, molecular bonding and/or mechanical bonding. The bonding need not be due to the presence of an adhesive. The one or more layers may be on or partially or fully embedded in a surface of the moulded material.

The material may be a plastic material. The plastic material may be a thermoplastic material. The thermoplastic material may be polypropylene. The thermoplastic material may be polyethylene. The moulded part may be rigid or flexible.

At least one of the one or more layers may include a polymeric material. At least one of the one or more layers may include a metal. At least one of the one or more layers may include a ceramic material. At least one of the one or more layers may include a biomaterial such as poly(lactic acid).

The outermost of the one or more layers may be an encapsulating layer. For example, this can be for durability and/or safety.

At least one of the one or more layers may include a region for enabling an electrical connection to be made to the one or more electronic components.

At least one of the one or more electronic components may include an organic (or, in other words, plastic or polymer) electronic component.

At least one of the one or more electronic components may include first and second electrode layers and an active layer therebetween.

At least one of the first and second electrodes may be a transparent electrode. At least one of the first and second electrodes may include a conductive polymer. The conductive polymer may be poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate). A dielectric layer may be included between the first and/or second electrode layers and the active layer.

The one or more electronic components may include an electroluminescent device.

The one or more electronic components may include a photovoltaic device and/or a battery.

There may be provided a modular system including two or more of the parts.

Brief Description of the Drawings

Certain embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 schematically illustrates a part with a bottom-emitting electroluminescent device.

Figure 2 schematically illustrates a part with a top-emitting electroluminescent device.

Figure 3 illustrates a mould cavity in a mould of an injection moulding apparatus for making a part such as that shown in Figure 1b. A top view and two side views are shown.

Figure 4 is an image of a moulded part with an integral electronic component and of the mould from which the part has been ejected. The image is to show that the part has been cleanly ejected from the mould.

Figure 5 is an image of the light emitted by an electroluminescent device in a part manufactured using a first method, which involves screen printing.

Figure 6 is an image of the light emitted by an electroluminescent device in a part manufactured using a second method, which involves airbrushing.

Figure 7a is an image, taken from the top, of the light emitted by an electroluminescent device in a part manufactured using a third method, which involves injection moulding.

Figure 7b is an image, taken from the side, of the part shown in Figure 7a.

Figure 8 is a graph showing the mean illuminance of parts manufactured using the first, second and third methods under different test conditions.

Figure 9 is an image of a cross-section through a part manufactured using the first method.

Figure 10 is an image of a cross-section through a part manufactured using the second method.

Figure 11 is an image of a cross-section through a part manufactured using the third method.

Figure 12 is a graph showing average layer thicknesses in the parts shown in Figures 9, 10 and 11.

Figure 13 schematically illustrates an apparatus for manufacturing a moulded part with one or more integral electronic components. The apparatus is illustrated in different states corresponding to different stages in the method shown in Figure 14.

Figure 14 is a flow diagram of a method of manufacturing a moulded part with one or more integral electronic components.

Detailed Description of the Certain Embodiments

Referring to Figure 1, a part 10 with one or more electronic components 10a is shown. In this example, the one or more electronic components 10a correspond to an electroluminescent device 10a. The part 10 is obtainable by several of the methods described herein. The part 10 includes a substrate 10b and one or more layers 11. In this example, the part 10 includes a first layer 11_1, a second layer 11_2, a third layer 11_3, a fourth layer 11_4 and a fifth layer 11_5 on the substrate 10b. However, the part 10 may include fewer or more layers 11. In this example, all of the layers 11 are part of the electroluminescent device 10a. However, one or more layers 11 may not be part of the one or more electronic components 10a. For example, one of the layers 11 may be an encapsulating layer.

The first layer 11_1 includes a conductive polymeric material, namely poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS). The first layer 11_1 acts as a transparent electrode layer. The second layer 11_2 includes one or more regions of silver on the substrate 10b along one or more sides of the first layer 11_1. The regions are in electrical contact with the first layer 11_1. The second layer 11_5 acts as a busbar to ensure even charge distribution across the first layer 11_1 when the device 10a is in use. The third layer 11_3 includes a phosphor material and acts as a light-emitting layer. The fourth layer 11_4 includes a ceramic material and acts as a dielectric layer. The fifth layer

11_5 includes silver and acts as a rear electrode layer. The substrate 10b is a plastic material such as polyethylene.

Electrical connections 12 can be made to the part 10. In particular, a first electrical connection 12_1 can be made to the busbar 11_2, at least a part of which is not covered by any of the other layers 11. A second electrical connection 12_2 can be made to the rear electrode 11_5.

The part 10 (10′) includes an electroluminescent device 10a (10a′) in the form of a bottom-emitting electroluminescent device. Light is emitted through the transparent electrode layer 11_1 at the bottom of the device 10a (10a′) and then through the substrate 10b.

Referring to Figure 2, a part 10 (10′′) including a top-emitting electroluminescent device 10a (10a′′) is shown. Here, the order of the first, third, fourth and fifth layers 11_1, 11_3, 11_4, 11_5 on the substrate 10b is reversed and so light is emitted through the transparent electrode layer 11_1 at the top of the device 10a (10a′′). This configuration is preferable when the substrate 10b is opaque, for example when the substrate 10b includes polypropylene. The rear electrode layer 11_5, which is the lowermost layer 11, has an extended region which is not covered by any of the other layers 11 so that a first electrical connection 12_1 can be made to it. The busbar layer 11_2 is provided on the substrate 10b and in electrical contact with the transparent electrode layer 11_1. A second electrical connection 12_2 can be made to the busbar 11_2.

Using a first method, a part 10 (10′) with a bottom-emitting electroluminescent device 10a (10a′) was produced by sequentially screen printing first, second, third, fourth and then fifth layers 11_1, 11_2, 11_3, 11_4, 11_5 onto a substrate 10b.

The layers 11 were formed from commercially-available materials. A CLEVIOS™ PEDOT:PSS-based conductive polymer paste was used to form the transparent electrode layer 11_1. This was obtained from H C Starck (Germany) and is now obtainable from Heraeus (Germany). Parts 10 were also manufactured using the first, second and third methods described herein using other PEDOT:PSS pastes such as Orgacon™ paste (obtained from AGFA materials). These parts 10 were found to have similar properties. A phosphor paste including $ZnS:Al_2O_3$ and a Cu activator was used to form the light emitting layer 11_3. A ceramic paste was used to form the dielectric layer 11_4. A silver paste was used to form the busbar layer 11_2 and the rear electrode layer 11_5. These three pastes were all obtained from Electra Polymers (UK). The substrate 10b was a flat, 3-mm-thick Lexan™ polycarbonate sheet. This is a clear material.

The layers 11 were screen printed by using a squeegee to force the paste through a screen. The screen included a piece of mesh stretched over a frame. Masks were used to control the size, shape and position of the layers 11.

After printing each layer 11, the device 10 was heated in an oven to dry and/or cure the layer 11. A heating regime recommended by the manufacturers of the layer material was used. The heating regimes are shown in Table 1.

Table 1: Heating regimes used in the first, second and third methods.

	First method		Second method		Third method	
	Oven Temperature (°C)	Time (s)	Oven Temperature (°C)	Time (s)	Mould Temperature (°C)	Time (s)
PEDOT:PSS	130	900	130	300	65-70	120-150
Phosphor	130	180	130	120	65-70	90-120
Dielectric	130	240	130	150	65-70	120-150
Silver	130	120	130	90	65-70	60-90

Using a second method, a part 10 (10′) with a bottom-emitting electroluminescent device 10a (10a′) was produced by sequentially airbrushing first, second, third, fourth and then fifth layers 11_1, 11_2, 11_3, 11_4, 11_5 onto a substrate 10b.

The pastes used in the first method were also used in the second method. However, the pastes were modified to make them suitable for airbrushing (for example so that they had a viscosity of around 35 to 60 centipoise). The pastes were diluted using a suitable solvent, namely methyl ethyl ketone (MEK). This solvent was selected by comparing the functional groups of various solvents with the functional groups of the layer materials. A mixing ratio of two-parts MEK to one-part paste was used. This ratio was determined by experiment.

The substrate 10b used in the first method was also used in the second method.

The airbrushing was performed using a dual-action airbrush with push button activation. The airbrush had a nozzle diameter of 0.30 mm. The layer materials were provided from 22 cm^3 glass jars with suction lids. A different jar was used for each layer material. The airbrush was used with a compressor with an air output of 23 litres per minute and a working pressure of 3 to 4 bar.

Masks were used to control the size, shape and position of the layers 11.

After depositing each layer 11, the device 10 was heated in an oven to dry and/or cure the layer 11. A modified heating regime which had been established for the modified layer material was used. The heating regimes are shown in Table 1.

Using a third method, a part 10 (10′′) with a top-emitting electroluminescent device 10a (10a′′) was produced by sequentially airbrushing first, third, fourth, fifth and then second layers 11_1, 11_3, 11_4, 11_5, 11_2 onto a part of a mould and then injection moulding a substrate 10b over the layers 11.

Referring to Figure 3, a mould cavity 30 in a mould 40 (Figure 4) is shown. The mould cavity 30 has various features, including flat regions 30a, shallow (40- to 100-mm radius) curved regions 30b and sharp (1-mm radius) curved edges 30c. A part of the mould 40 is shown in Figure 4.

Before depositing the first layer 11_1, a release agent, namely ACMOS 82-2405 release agent, was applied to the mould 40.

Masks were positioned over the mould 40 to control the size, shape and position of the layers 11. The masks had been moulded using the mould 40 and so the mask and the mould 40 had corresponding surfaces.

The materials used in the second method for forming the layers 11 were also used in the third method. The same airbrush was also used.

After depositing each layer 11, the device 10 was heated to dry and/or cure the layer 11. The heat was applied by heating the mould 40 using electric cartridge heaters. The heating regimes are shown in Table 1. Drying times varied slightly between samples due to variations in the thicknesses of the layers 11 and the temperature of the mould 40.

After applying, and heating, the fifth layer 11_5, an injection moulding process was carried out to form the substrate 10b over the layers 11.

The injection-moulding machine used was a Sandretto Micro 30.

Polypropylene was used as the injection-moulding material. Polypropylene is a cheap, commodity plastic and is stable. It also does not require any pre-drying and can be processed at relatively low temperatures. Polypropylene is an opaque material.

The injection-moulding process was carried out using an injection pressure of 1950 bar.

Finally, the part 10 was ejected from the mould 40.

Referring to Figure 4, the ejected part 10 and the mould 40 are shown. The slight residue which can be seen in the mould 40 is the release agent, rather than any of the materials used to form the layers 11. Thus, the layers 11 and the substrate 10b have adhered well to one another.

Referring to Figures 5, 6 and 7 (a and b), the light emitted by examples of parts 10 produced using the first, second and third methods respectively are shown. Suitable alternating voltages were applied between the electrodes 11_1, 11_5 to cause the electroluminescent devices 10a to emit the light.

Illuminance measurements were performed on examples of parts 10 made using the first, second and third methods. These particular parts 10 included flat, 4 x 4 cm electroluminescent devices 10a.

An alternating current (AC) power supply with a variable-frequency and variable-voltage output (100 to 400 Hz; 100 to 300 V RMS) was used. A Velleman HPS10 handheld oscilloscope was used to measure the frequency and RMS voltage of the output.

A Reed ST-1301 light meter was used to measure the illuminance of the part 10. A holder was used to hold the light meter in a fixed position relative to the electroluminescent device 10a.

Measurements were performed under first, second, third and fourth test conditions. The test conditions involved different voltages (V) and/or frequencies (F), as shown in Table 2.

Table 2. The different test conditions

Test condition	F (Hz)	V (V RMS)
1st	400	300
2nd	100	300
3rd	400	100
4th	100	100

For each measurement, the alternating voltage was applied for 60 seconds before the reading was taken. This was because the light emitted by the device 10 increased in intensity when the voltage was first applied but reached a steady-state in less than 60 seconds. Five samples of each part 10 were measured. The measurements were repeated five times for each sample.

The results of the illuminance measurements are shown in Tables 3a, 3b and 3c and in Figure 8.

Table 3a. Illuminance of parts made using the first method

Test condition	Illuminance (lx)				Relative standard deviation (%)
	Mean	Standard deviation (SD)	Mean – SD	Mean + SD	
1st	168.96	13.03	155.93	181.99	7.71
2nd	56.92	4.30	52.62	61.22	7.56
3rd	18.88	3.87	15.01	22.75	20.47
4th	7.36	1.47	5.89	8.83	19.95

Table 3b. Illuminance of parts made using second method

Test condition	Illuminance (lx)				Relative standard deviation (%)
	Mean	Standard deviation (SD)	Mean – SD	Mean + SD	
1st	287.9	35.21	252.68	323.12	12.23
2nd	80.8	5.85	74.95	86.65	7.23
3rd	66.85	6.72	60.13	73.57	10.06
4th	21.71	1.68	20.04	23.39	7.73

Table 3c. Illuminance of parts made using the third method

Test condition	Illuminance (lx)				Relative standard deviation (%)
	Mean	Standard deviation (SD)	Mean – SD	Mean + SD	
1st	44.67	14.22	30.44	58.89	31.85
2nd	19.75	7.32	12.43	27.07	37.06
3rd	12.00	4.69	7.31	16.69	39.09
4th	7.33	3.07	4.26	10.41	41.96

The basic airbrushed parts 10, that is to say those produced using the second method, had a higher illuminance than the screen-printed parts 10, that is to say those produced using the first method. The moulded parts 10, that is to say those produced using the third method, had the lowest illuminance.

The first test condition (400 Hz, 330 V RMS) gave the highest illuminances. Under the first test condition, the screen-printed parts 10 had a mean illuminance of 169.0 ± 13.0 lx and the basic airbrushed parts 10 had a mean illuminance of 287.9 ± 35.2 lx. Thus, the basic airbrushed parts 10 are around 70 % brighter than the screen-printed parts 10. Under the first test condition, the moulded parts 10 had a mean illuminance of 44.7 ± 14.2 lx, that is to say around 15 % of the illuminance of the basic airbrushed parts 10.

Referring to Figures 9, 10 and 11, cross-sections through examples of parts 10 produced using the first, second and third methods respectively are shown. The parts 10 are examples of those on which the illuminance measurements were performed.

The parts 10 were sectioned, mounted and polished, and then viewed using a Zeiss AxioLab A1 microscope.

The screen-printed part 10 and the basic airbrushed part 10 have a relatively even layer structure. In contrast, the moulded part 10 has a relatively uneven layer structure.

The screen-printed part 10 and the basic airbrushed part 10 have voids 90 in the phosphor layer 11_3 and/or at the interface between the phosphor layer 11_3 and the PEDOT:PSS layer 11_1. In contrast, the moulded part 10 does not have any voids. The parts 10 were all prepared for microscopy in the same way. Thus, the voids 90 in the screen-printed part 10 and the basic airbrushed part 10 are likely to have been formed when these parts 10 were produced.

The voids 90 are indicative of suboptimal formation of phosphor layer 11_3 and/or suboptimal adhesion between the phosphor layer 11_3 and the PEDOT:PSS layer 11_1.

The absence of voids in the moulded part 10 can be attributed to the high pressure associated the injection-moulding process (1950 bar) having the effect of eliminating any voids created when the layers 11 were formed.

Referring to Figure 12, average thicknesses of the layers 11 in the parts 10 are compared.

AxioVision 4.8 software was used to measure the thicknesses of the layers 11.

The average layer thicknesses were similar in the basic airbrushed parts 10 and the moulded parts 10 (in which the layers 11 were also formed by airbrushing). Despite this, as described hereinbefore, the moulded parts 10 have a considerably lower illuminance than the basic airbrushed parts 10 (see Figure 8). Furthermore, the moulded parts 10 have a lower-quality layer structure than the basic airbrushed parts 10 (see Figures 10 and 11). These differences may be due to the lower temperatures used to dry and/or cure the layers 11 in the moulded parts 10. They may also be due to the movement of the polypropylene material over the layers 11 during the injection-moulding process.

Referring to Figures 13a to 13g, apparatus 100 for manufacturing an injection-moulded part 10 with one or more integral electronic components 10a is shown.

In this example, the apparatus 100 includes an injection-moulding machine 101 with a reciprocating screw 101a. However, the apparatus 100 may include another type of injection-moulding machine.

The apparatus 100 includes a mould 102. The mould 102 includes a first mould part 102a and a second mould part 102b. The mould 102 can be opened or closed by moving the first and second mould parts 102a, 102b in relation to each other. The mould 102 includes a sprue 102c through which the material 110 to form the substrate 10b is injected into the mould 102.

The mould 102 may be coated with a coating such as polytetrafluoroethylene (PTFE). This may reduce the need to use a release agent and/or may improve the surface finish of the part 10.

In this example, a single mould 102 with a single cavity 102d is shown. However, there may be plural moulds 102 and/or cavities 102d.

The apparatus 100 also includes a device 103 for forming one or more layers 11 on the mould 102 (hereinafter referred to as a “layer-forming device”).

The layer-forming device 103 may include a section 104 for each of the layers 11 to be formed.

In this example, the device 103 includes four sections 104, each of which is for forming a respective layer 11 by spray deposition. For clarity, only one section 104 is shown. However, the device 103 may include fewer sections 104 or more sections 104. The device 103 may include sections 104 of another type. The device 103 may include two or more types of section 104. This will depend upon the layers 11 to be formed. Sections 104 can be added to or removed from the apparatus 100.

The section 104 includes a head 104a and a mask 104b. The head 104a and the mask 104b may be movable in relation to each other. In some examples, the heads 104a and the masks 104b may be independently movable. The section 104 includes or is in communication with a source (not shown) of the material 111 to form the layer 11. In this example, the section 104 includes an airbrush. Thus, it also includes or is in communication with a source (not shown) of compressed air.

The sections 104 are movable into and out of the open mould 102. The sections 104 may be mounted on a movable plate (not shown). The plate may rotate to move a particular one of the sections 104 into a position for forming the layer 11. The sections 104 may be independently movable, for example by robotic arms.

In some examples, the sections 104 need not be movable. For example, the sections 104 may be fixed in suitable positions outside the mould 102 for forming the layers 11. The sections 104 (in particular the heads 104a) may be fixed in positions in the mould 102. The sections 104 (in particular the heads 104a) may be integral parts of the mould 102.

The spray is formed in the head 104a and exits the head 104a through one or more nozzles.

The head 104a may be stationary or can be moved while depositing the layer 11.

The properties (e.g. pressure) of the spray and the length of time during which the spraying is performed can be controlled to control the thickness of the layer 11. Typically, thicknesses may be between 200 nm and tens of microns. However, they may be more or less than this.

The mask 104b is for controlling the size, shape and position of the layer 11. The mask 104b may have a curved surface which follows the curves in the surface of the mould 102. Thus, the layers 11 can be deposited more accurately on a curved surface of the mould 102. In some examples, one or more of the sections 104 need not include masks 104b.

The apparatus 100 includes a heating arrangement 105 for heating and thus drying and/or curing the layers 11. In this example, the heating arrangement 105 heats the mould 102 which, in turn, heats the layers 11 formed thereon. The heating arrangement 105 is adapted to raise the temperature of the mould and hence one or more of the layers 11 to a suitable temperature for drying and/or curing it. For example, the temperature may be between 65 and 130 °C. The heating arrangement 105 may include channels in the mould 102 through which a hot fluid (for example water, steam or oil) can be passed. The heating arrangement 105 may include one or more electric heaters (for example cartridge heaters) arranged on the mould 102. In some examples, the apparatus 100 need not include a heating arrangement 105.

The injection-moulding machine 101 may correspond to a conventional injection-moulding machine.

The pressure at which the material 110 is injected into the mould 102 may be controlled in such a way as to remove any voids from the deposited layers 11. For example, the highest pressures which can be used without damaging the layers 11 may be established.

The position and/or alignment of the sprue 102c relative to the region in which the layers 11 are formed may be selected such that, when the material 110 is injected into the mould 102, the risk of damage to the layers 11 is minimised. For example, the material 110 may be injected in a direction away from the layers 11.

The apparatus 100 preferably includes a controller (not shown). The controller can control, for example, the opening and closing of the mould 102, the operation of the layer-forming device 103, the operation of the heating arrangement 105, and/or the operation of the injection-moulding machine 101. The controller may include a computer. The controller can be programmed so as to enable, for example, a plurality of parts 10 to be manufactured with the same or different layer structures 11 and hence electronic capabilities.

Referring to Figures 13a to 13g and Figure 14, a method of manufacturing a moulded part 10 with one or more integral electronic components 10a is shown. In this example, the method is performed by the apparatus 100. However, the method 100 may be performed by another type of apparatus.

The method includes forming one or more layers 11 in the mould 102 (step S1).

The layer-forming device 103 and, in particular, the section 104 for depositing the first layer 11_1, is moved into a suitable position (step S1a). For example, the head 104a and the mask 104b may be aligned with the region of the mould 102 on which the layer 11_1 is to be formed.

The section 104a is then operated to deposit the layer 11_1 (step S1b). For example, the material 111 for forming the layer 11_1 may be sprayed for a predetermined length of time.

The heating arrangement 105 is then operated to heat the layer 11_1 (step S1c). Thermometry (not shown) may be included in the apparatus 100 and may be used to control the temperature to which the layer 11_1 is heated.

It is determined by the controller whether there are any more layers 11 to be formed (step S1d).

If there are more layers 11 to be formed, then these layers 11 are formed in a corresponding way to that described hereinbefore.

If there are no more layers 11 to be formed, then the layer-forming device 103 is removed from the mould 102 (step S1e).

Moulding is then carried out (step S2).

In particular, the mould 102 is closed (step S2a).

The injection-moulding machine 101 is operated to inject the material 110 for forming the substrate 10b into the mould 102 (step S2b).

The mould 102 is then opened and the part 10 is ejected from the mould 102 (step S2c). This may be done using ejection pins 106. The opening of the mould 102 and the ejection of the part 10 may be delayed to allow the part 10 to cool.

It is determined by the controller whether there are any more parts 10 to be formed (step S3). If there are more parts 10 to be formed, then these parts 10 are formed as described hereinbefore. If there are no more parts 10 to be formed, then the method ends.

Depending upon the apparatus 100 and/or upon the moulded part 10 being manufactured, certain operations need not be performed or may be performed in a different order. For example, the layer-forming device 102 may not be movable and so need not be moved into position (step S1a) or removed from the mould 102 (step S1e). The heating of the layers 11 (step S1c) need not be performed after forming each of the layers 11. The layer-forming device 102 may be fixed in the mould 102 and so the mould 102 may be closed (step S2a) before the layers 11 are formed (step S1).

Moulded parts 10 with integral electroluminescent devices 10a as described herein can have many different applications. They can be used as an alternative to conventional lighting systems. They can be used to in places where conventional lighting systems are disadvantageous due to their size, weight and/or cost. For example, objects such as glove boxes, cupboards, traffic control devices, safety clothing, phone casings, electrical sockets and so forth can be provided with built-in lighting capabilities.

It will be appreciated that many other modifications may be made to the embodiments hereinbefore described.

The moulded part 10 may be different.

For example, the part 10 may include a different electroluminescent device 10a. One or more of the layers 11 may include different materials. For example, the light-emitting layer 11_3 may include a different phosphor material and/or may emit a different colour of light. The transparent electrode layer 11_1 may include a different transparent conductive polymer material. The rear electrode 11_5 may include a different conductive material. The rear electrode 11_5 may include a transparent conductive material such as PEDOT:PSS. There may be no dielectric layers 11_4 or more than one dielectric layer 11_4. There may be a single layer including a mixture of a light-emitting material and a dielectric material.

The part 10 may include two or more electroluminescent devices 10a. Different regions of the part 10 may emit light in response to electrical signals being provided to different respective sets of electrical connections. Thus, the part 10 may form part of a display or a sign.

The part 10 may be provided with an encapsulating layer 11 for durability and/or safety. A material which adheres to the underlying layers 11 but not to the mould 102 is preferably selected for forming the encapsulating layer 11. The encapsulating layer 11 may be absent in certain regions, for example to enable electrical connections to be made to the part 10.

The substrate 10b may be moulded to have any suitable shape. For example, the substrate 10b may have a curved surface over which an electronic component 10a is formed. The substrate 10b may have a space for holding a battery or an additional electronic component such as an inverter. The substrate 10b may be rigid or flexible.

The part 10 may include one or more electronic devices 10a other than electroluminescent devices.

The part 10 may include an integral photovoltaic device 10a. The photovoltaic device 10a is preferably an organic photovoltaic device. The photovoltaic device 10a may have a similar layer structure to the electroluminescent device 10a and, in particular, may include a similar arrangement of two electrode layers and an intermediate active layer. Instead of a phosphor layer 11_3 as the active layer, the photovoltaic device 10a includes one or more materials which exhibit the photovoltaic effect. For example, the active layer may be formed from a poly(3-hexylthiophene):[6,6]-Phenyl C61 butyric acid methyl-ester (P3HT:PCBM) blend dissolved in a co-solvent mixture. This material can also be spray deposited, for example using an airbrush. Thus, the methods and apparatuses described herein can be readily used to manufacture a part 10 with an integral photovoltaic device 10a.

The part 10 may include an integral battery 10a. The battery 10a is preferably an organic battery. For example, the battery 10a may be an organic radical battery. Such a battery 10a may also be manufactured using the methods and apparatuses 100 described herein.

A part 10 may include, for example, an integral photovoltaic device 10a, a battery 10a and an electroluminescent device 10a. In this way, the part 10 can be used to generate electricity during the daytime, store the energy, and then illuminate at night.

The part 10 may be a sensor. For example, the part 10 may include a smart material, such as a shape-memory polymer, which interacts with integral electronic components 10a.

The part 10 may include an integral radio-frequency identification (RFID) tag 10a.

The part 10 may include one or more integral electronic components 10a such as transistors, capacitors, electrical connections, and so forth.

A modular system including two or more of the parts 10 may be produced.

For example, the modular system may include two or more parts 10 with integral photovoltaic devices 10a. The parts 10 can be connectable to one another so that electrical connections can be made therebetween in such a way that the electrical output of one part 10 is added to the output of the other. Thus, a photovoltaic device can be assembled with any size and shape, depending upon the number of parts 10 and how they are connected together.

The modular system may include a part 10 with an integral photovoltaic device 10a and/or a part 10 with an integral battery 10a and a part 10 with an integral electroluminescent device 10a, which are operatively connectable to one another.

At least some of the materials in the part 10 may be biodegradable or compostable. At least some of the materials in the part 10 may be biocompatible. At least some of the materials in the part 10 may be bioresorbable.

The manufacturing method and the apparatus 100 may be different from those hereinbefore described.

For example, instead of an airbrush, an ultrasonic or electrostatic atomizer may be used to form the spray.

One or more of the layers 11 may be formed using a process other than spray deposition. For example, an additive-manufacturing (3D-printing) process may be used. Other printing methods such as inkjet printing may be used.

Materials in the form of powders or nanopowders may be applied using a spray-coating process.

The layers 11 may be heated in a different way. For example, the mould 102 and/or the layers 11 may be heated using hot gases or steam or by non-contact methods such as electromagnetic induction, infrared radiation or electrical resistance. The mould 102 may subsequently be cooled using channel cooling. This can make the heating and cooling more rapid.

The method may involve a moulding process other than injection moulding. For example, it may involve compression moulding, blow moulding or the like.

Where the part 10 includes two or more different electronic components 10a, these can be produced from a single sequence of layers by using an appropriate sequence of masks 104b. In this case, there will be at least one layer 11 which has two or more different regions respectively included in two or more different electronic components 10a.

Claims

1. A method of manufacturing a moulded part with one or more integral electronic components, the method comprising:

forming one or more layers in a mould of a moulding apparatus, the one or more layers comprising the one or more electronic components; and

introducing material into the mould to form the moulded part with the one or more integral electronic components.

2. A method according to claim 1, comprising forming at least one of the one or more layers directly on the mould.

3. A method according to any preceding claim, comprising forming at least one of the one or more layers on a curved surface.

4. A method according to any preceding claim, comprising forming at least one of the one or more layers by spray deposition.

5. A method according to any preceding claim, comprising positioning a mask over the mould before forming at least one of the one or more layers.

6. A method according to any preceding claim, comprising heating at least one of the one or more layers before forming a next one of the one or more layers or before introducing the material into the mould.

7. A method according to any preceding claim, comprising forming the one or more layers with respective predetermined sizes, shapes and positions.

8. Apparatus for manufacturing a moulded part with one or more integral electronic components, the apparatus adapted to:

form one or more layers in a mould, the one or more layers comprising the one or more electronic components; and

introduce material into the mould to form the moulded part with the one or more integral electronic components.

9. Apparatus according to claim 8, comprising one or more sections for forming respective ones of the one or more layers.

10. A moulded part with one or more integral electronic components, wherein the part comprises moulded material and one or more layers comprising the one or more electronic components, at least one of the one or more layers being bonded to the moulded material, and wherein the part is obtainable by a method according to any one of claims 1 to 7.

11. A method according to any one of claims 1 to 7, apparatus according to claim 8 or 9, or part according to claim 10, wherein at least one of the one or more layers comprises a polymeric material.

12. A method according to any one of claims 1 to 7 and 11, apparatus according to any one of claims 8, 9 and 11, or part according to claim 10 or 11, wherein the outermost of the one or more layers is an encapsulating layer.

13. A method according to any one of claims 1 to 7, 11 and 12, apparatus according to any one of claims 8, 9, 11 and 12, or a part according to any one of claims 10 to 12, wherein at least one of the one or more electronic components comprises first and second electrode layers and an active layer therebetween.

14. A method according to any one of claims 1 to 7 and 11 to 13, apparatus according to any one of claims 8, 9 and 11 to 13, or a part according to any one of claims 10 to 13, wherein the one or more electronic components comprise an electroluminescent device.

15. A method according to any one of claims 1 to 7 and 11 to 14, apparatus according to any one of claims 8, 9 and 11 to 14, or a part according to any one of claims 10 to 14, wherein the one or more electronic components comprise a photovoltaic device and/or a battery.

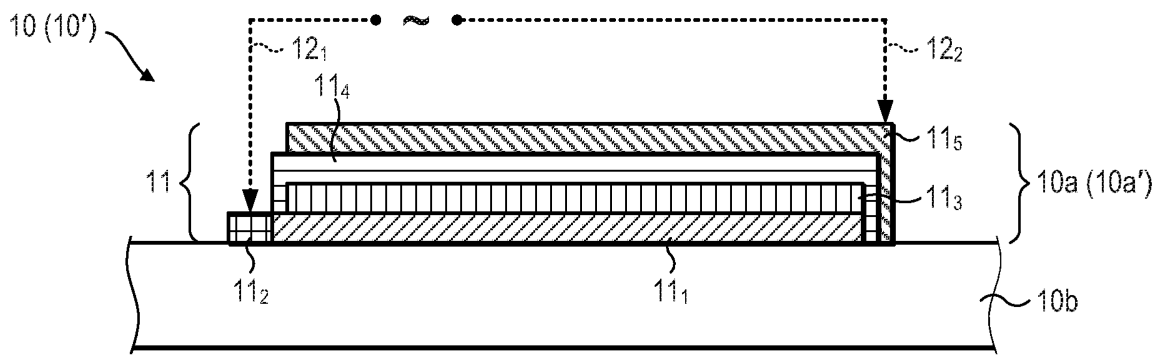
10 (10′)
12₁
12₂
11₄
11₅
11
11₃
10a (10a′)
11₂
11₁
10b

Fig. 1

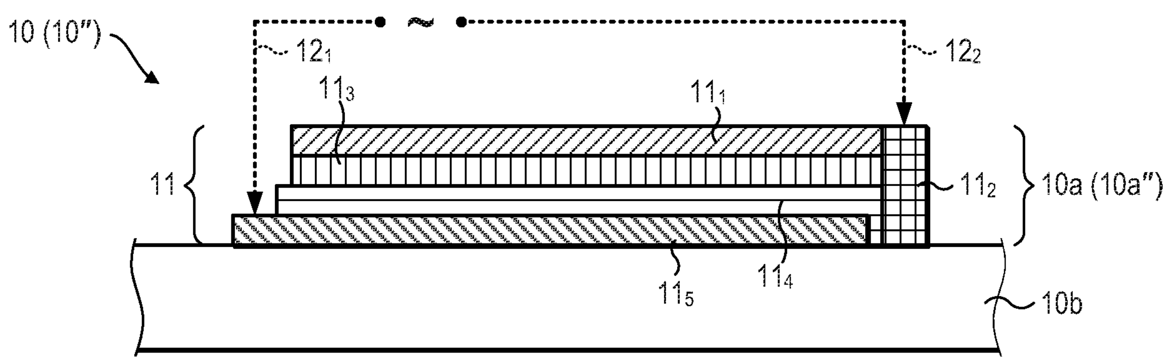
10 (10″)
12₁
12₂
11₃
11₁
11
11₂
10a (10a″)
11₅
11₄
10b

Fig. 2

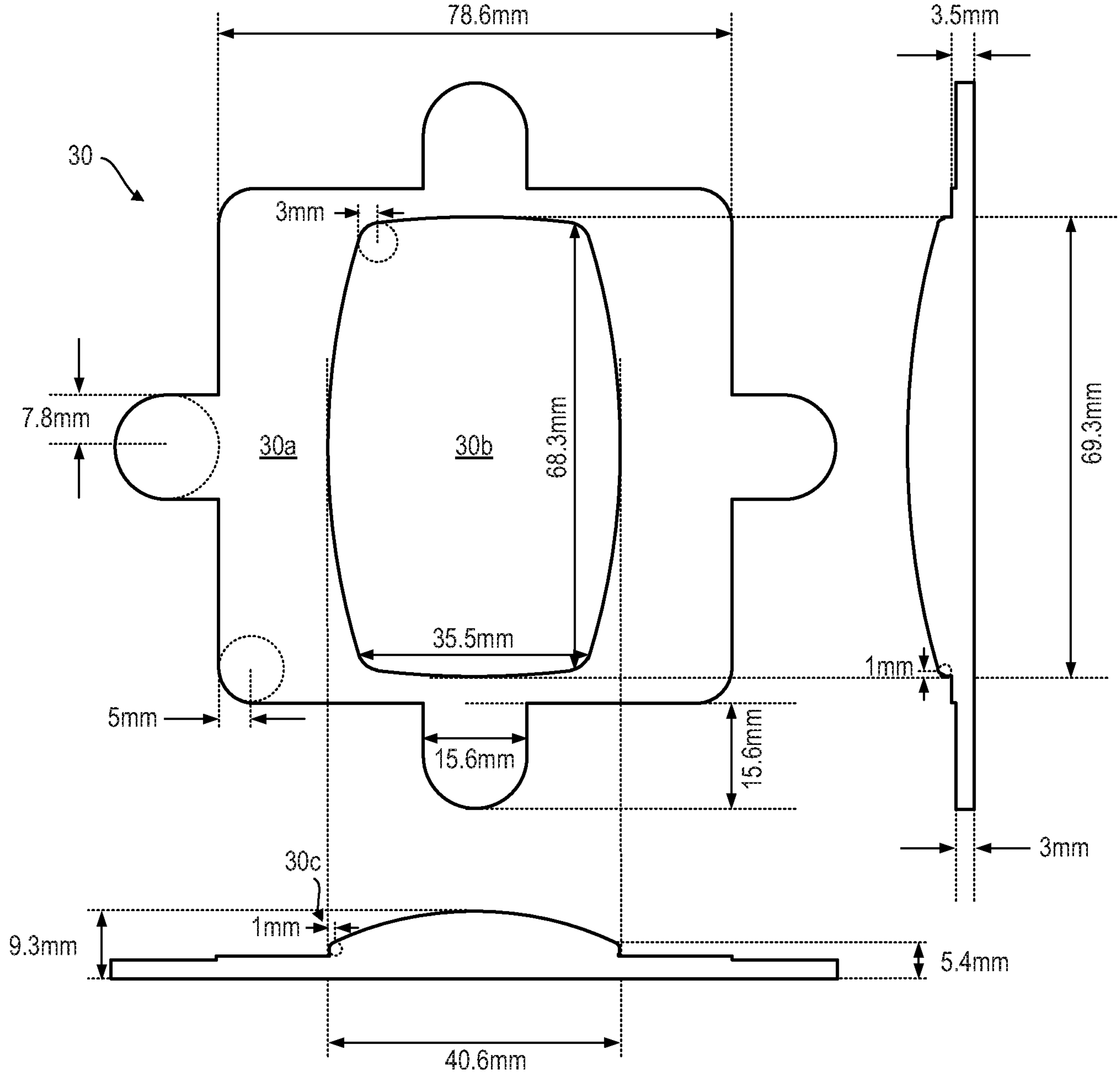
78.6mm
3.5mm
30
3mm
7.8mm
30a
30b
68.3mm
69.3mm
35.5mm
1mm
5mm
15.6mm
15.6mm
3mm
30c
9.3mm
1mm
5.4mm
40.6mm

Fig. 3

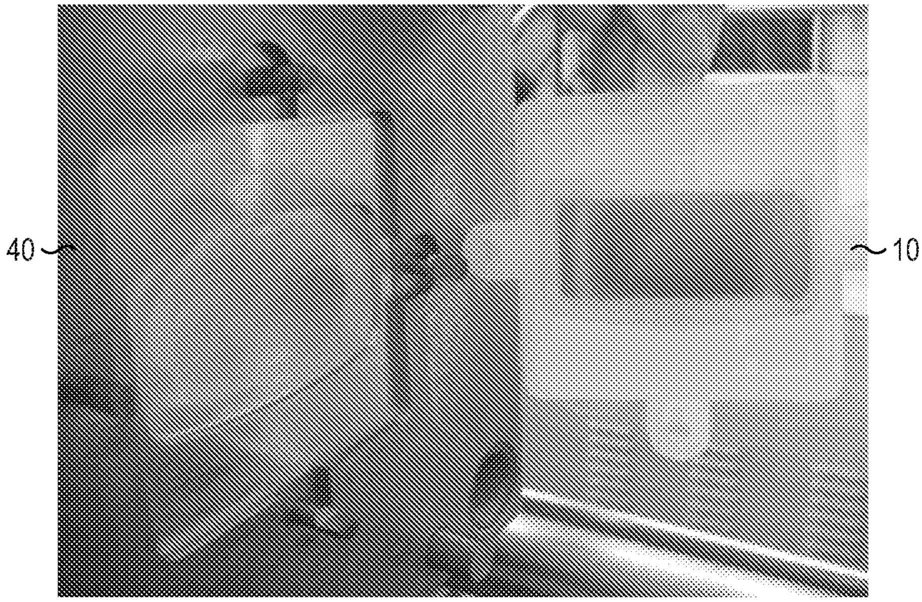

Fig. 4

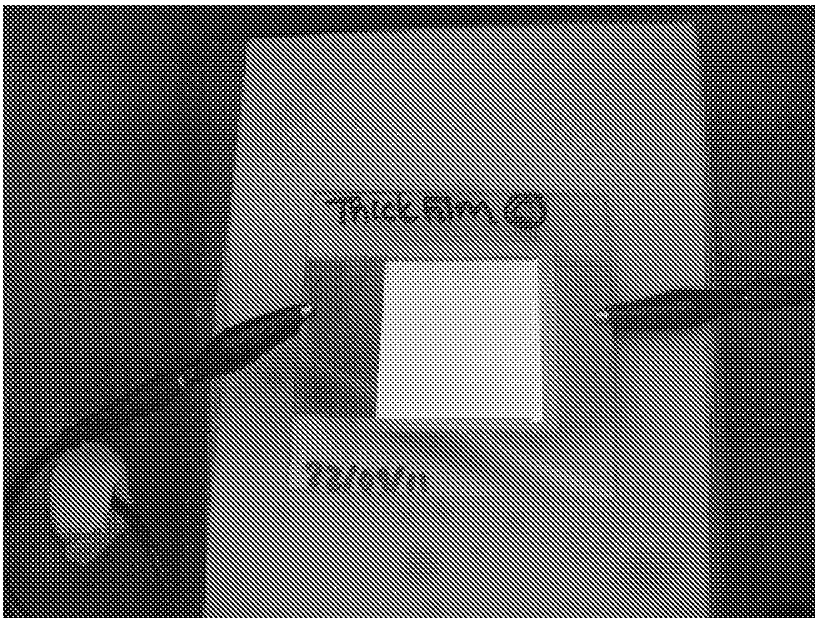

Fig. 5

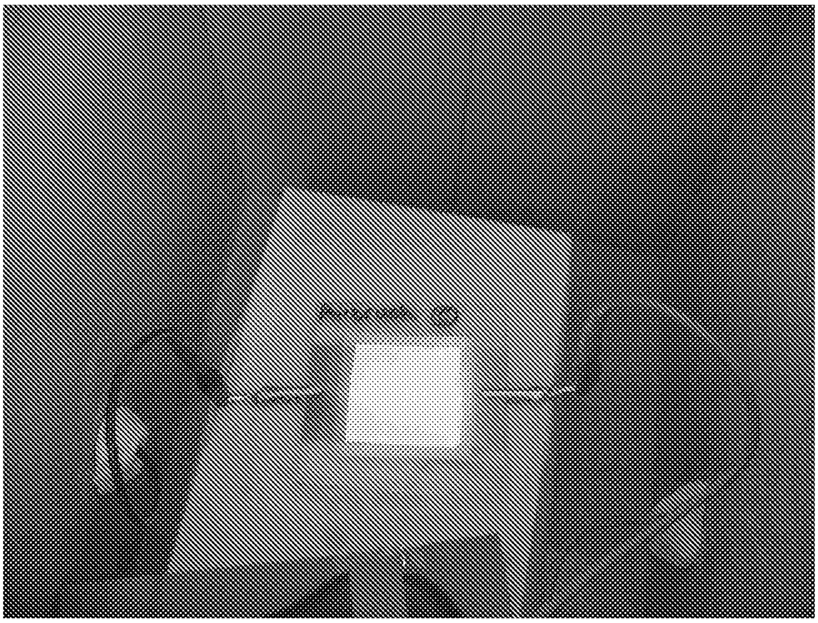

Fig. 6

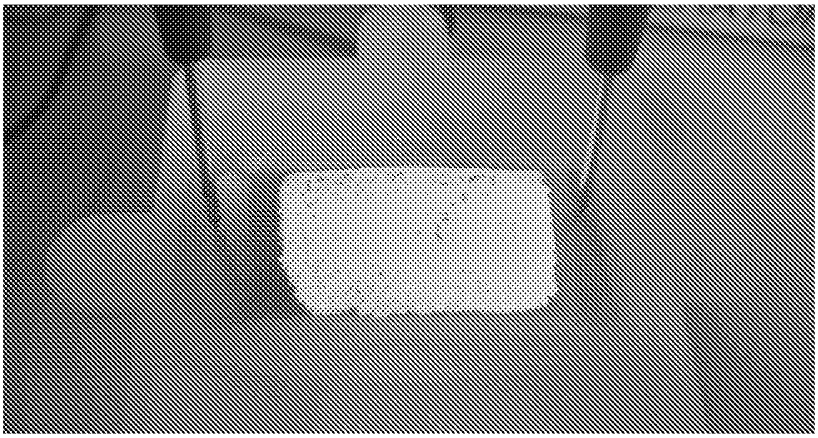

Fig. 7a

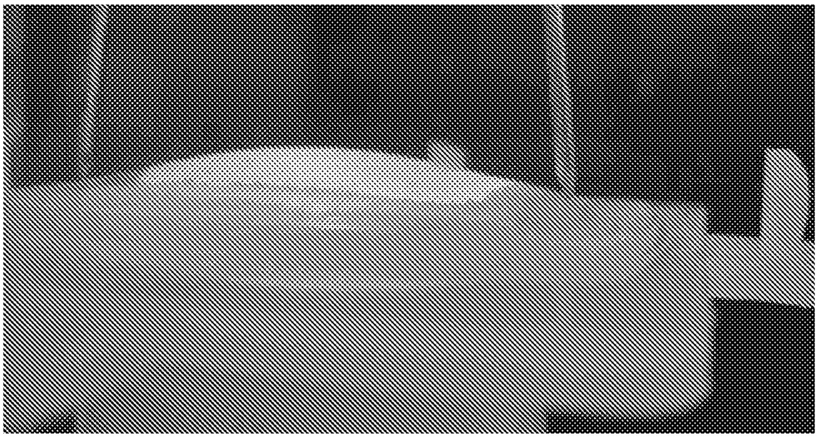

Fig. 7b

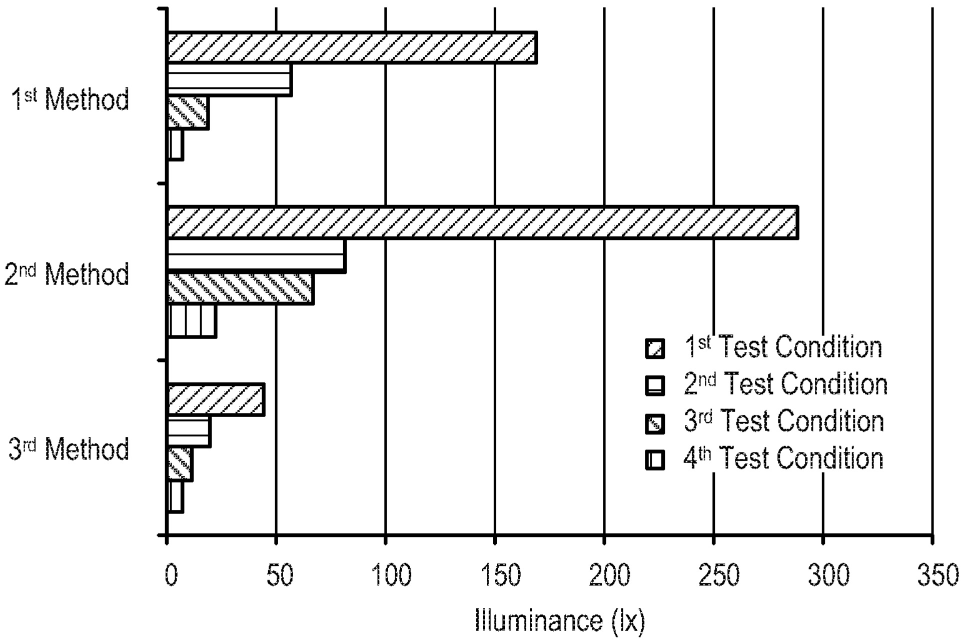
1st Method
2nd Method
3rd Method
1st Test Condition
2nd Test Condition
3rd Test Condition
4th Test Condition
0
50
100
150
200
250
300
350
Illuminance (lx)

Fig. 8

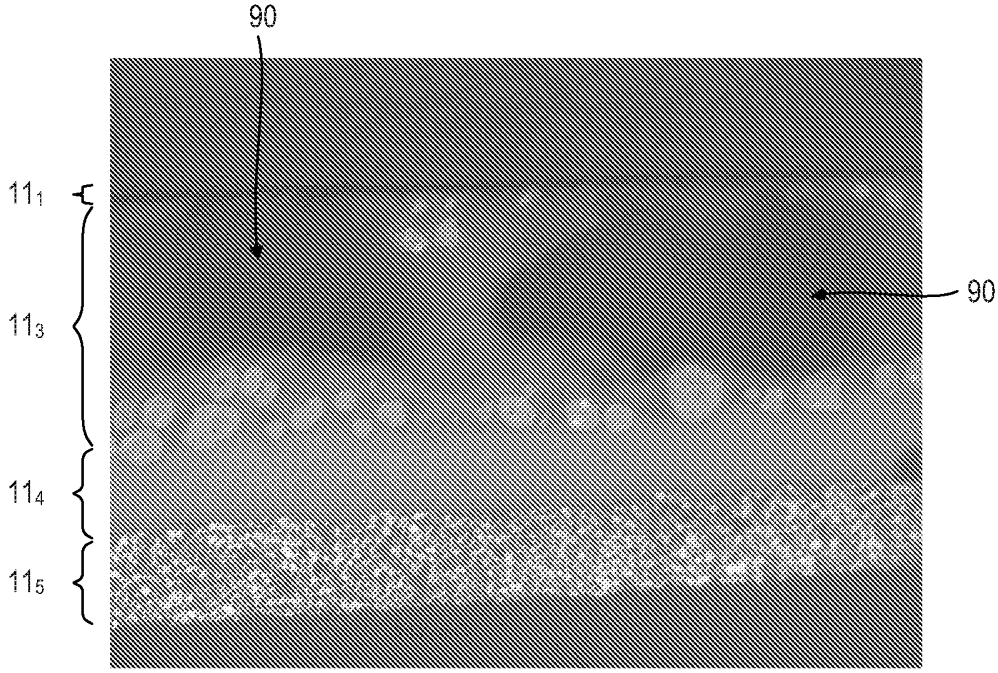
90
90
11_1
11_3
11_4
11_5

Fig. 9

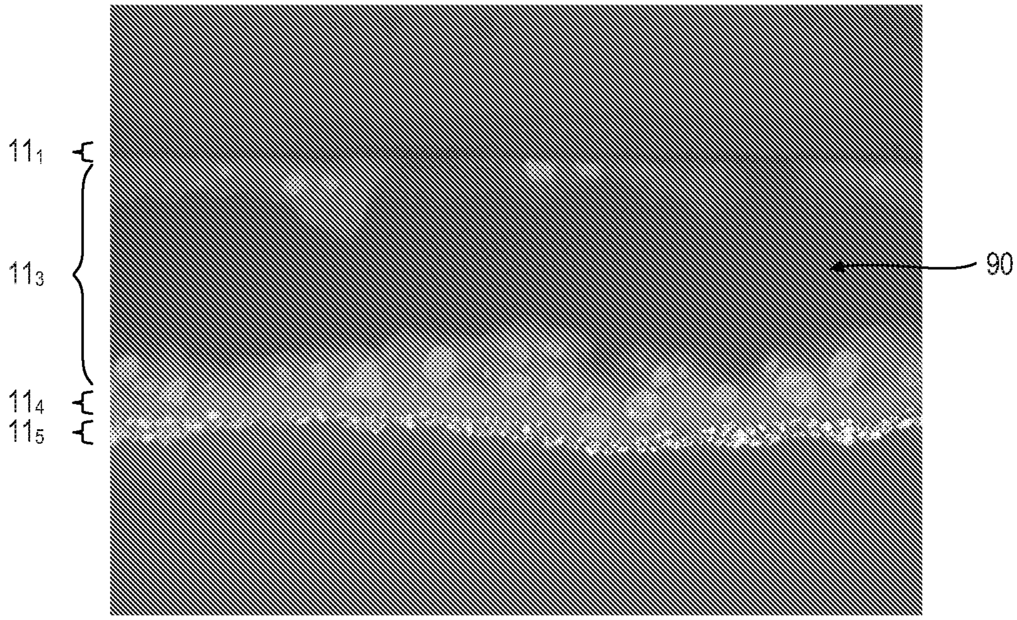

Fig. 10

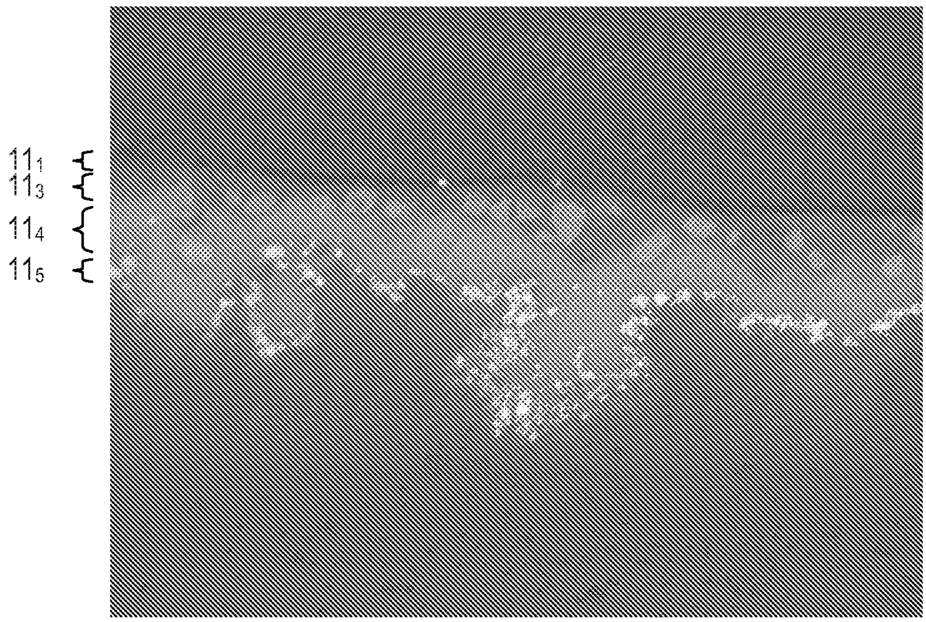

Fig. 11

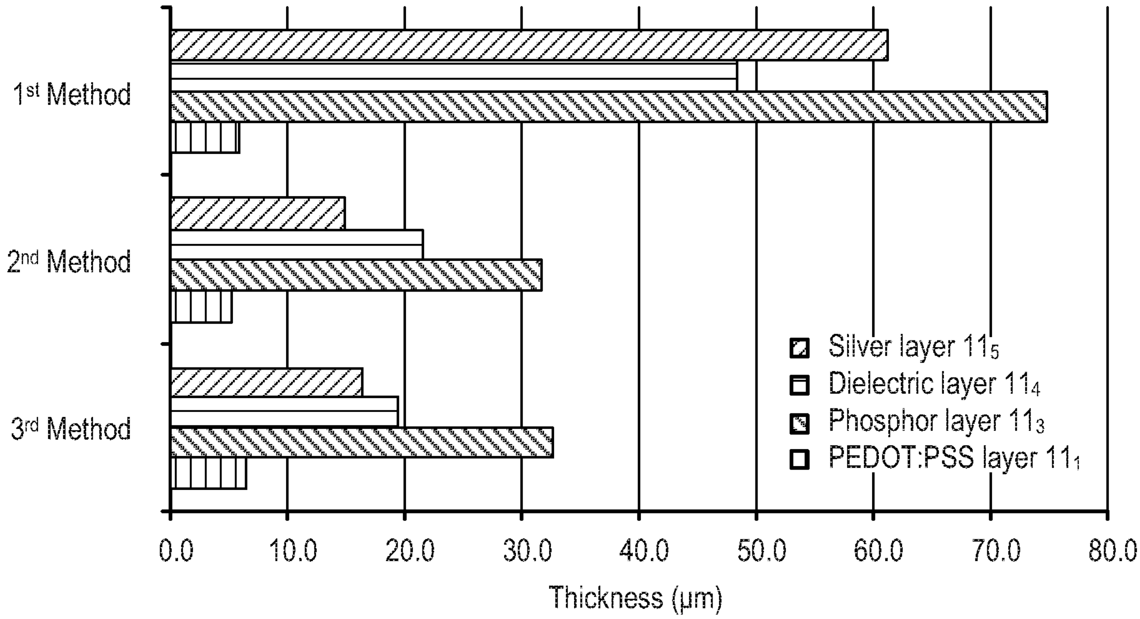
1st Method
2nd Method
3rd Method
Silver layer 11₅
Dielectric layer 11₄
Phosphor layer 11₃
PEDOT:PSS layer 11₁
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
Thickness (μm)

Fig. 12

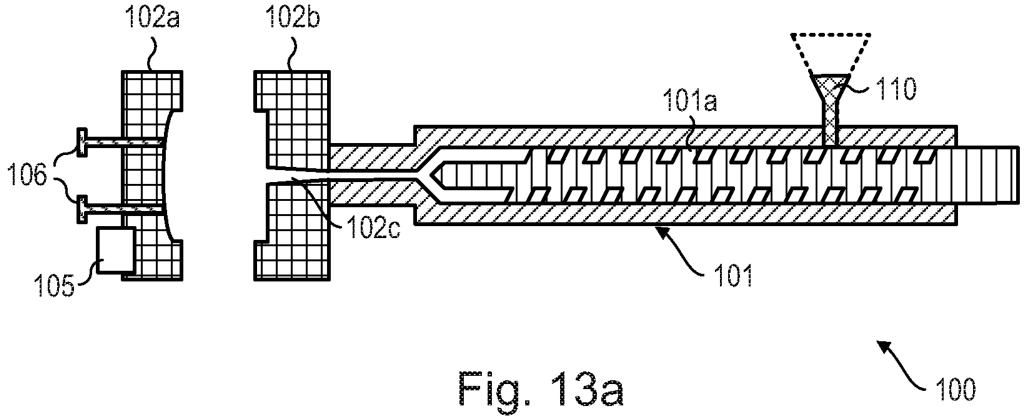

Fig. 13a

S1a

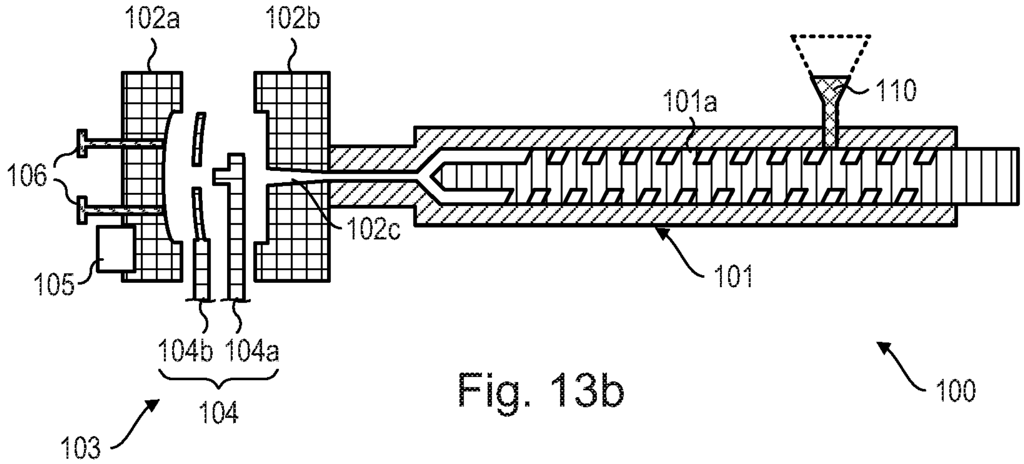

Fig. 13b

S1b

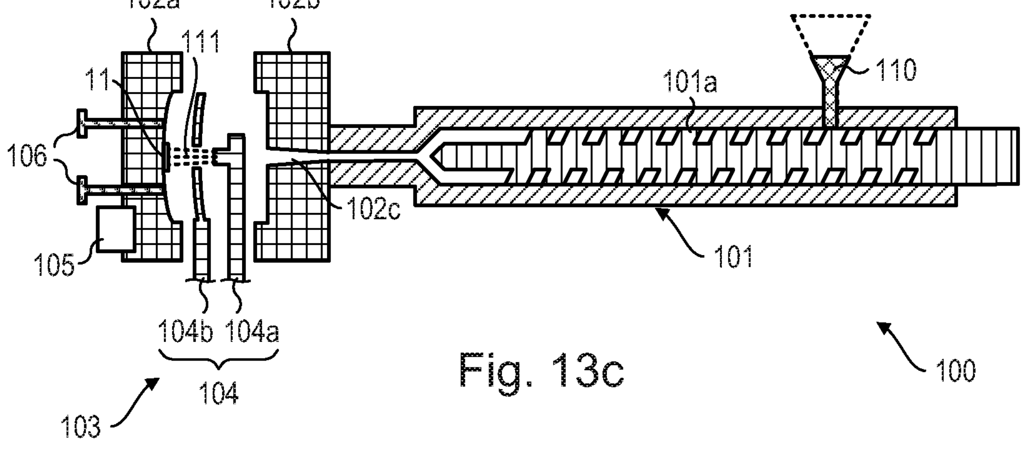

Fig. 13c

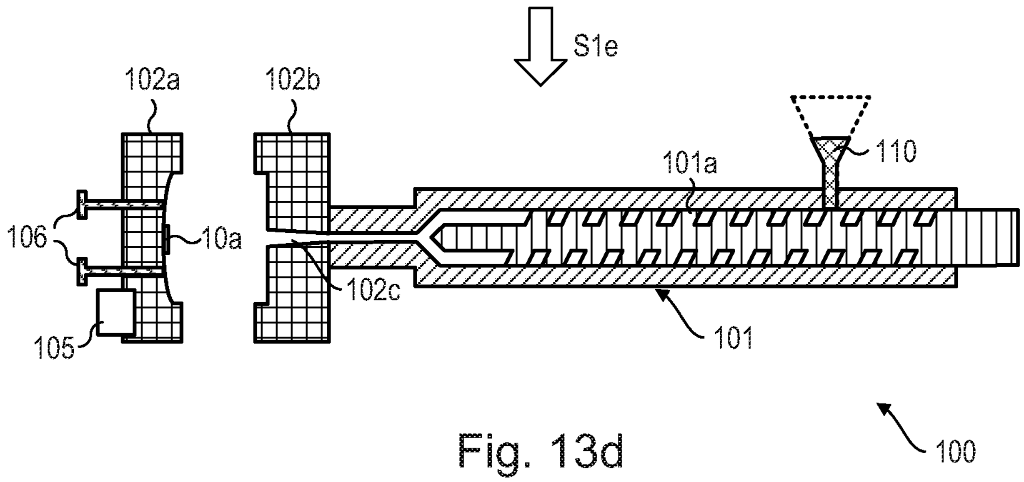

Fig. 13d

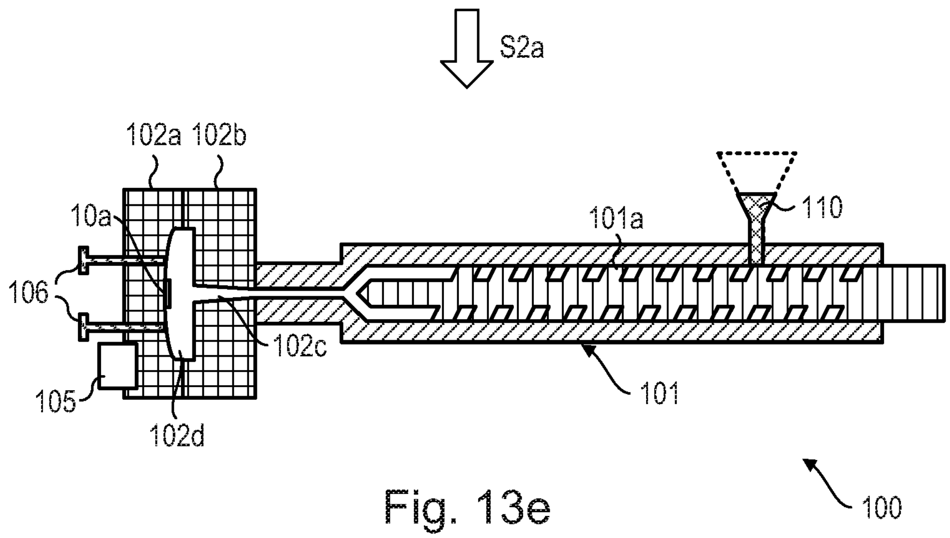

Fig. 13e

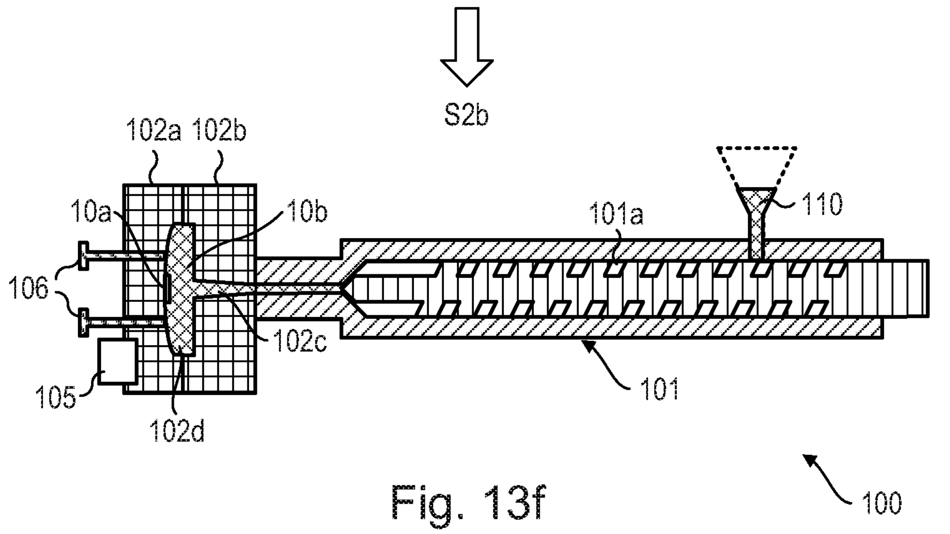

Fig. 13f

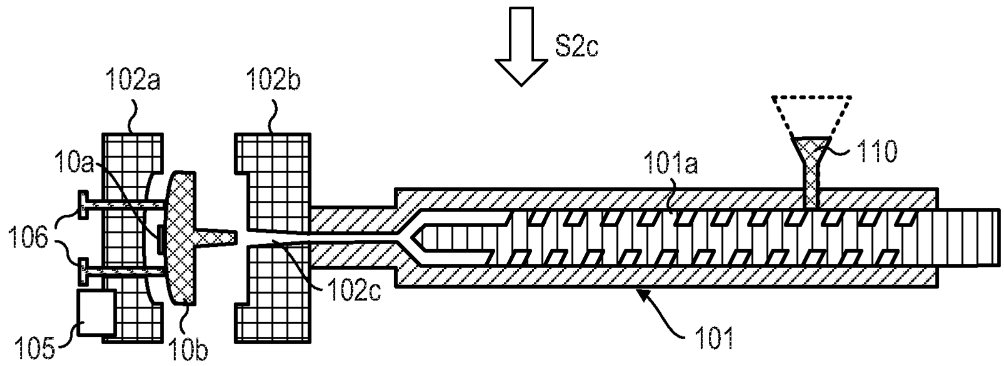

Fig. 13g

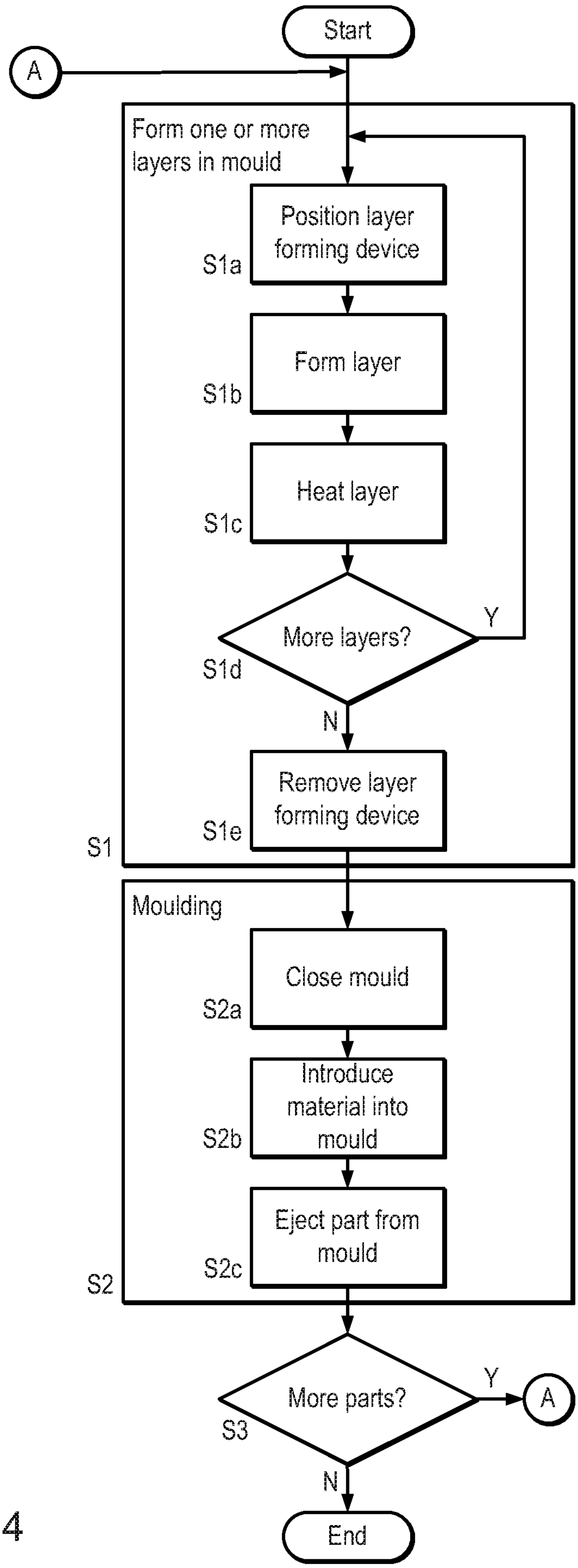
Start
A
Form one or more layers in mould
Position layer forming device
S1a
Form layer
S1b
Heat layer
S1c
More layers?
Y
S1d
N
Remove layer forming device
S1e
S1
Moulding
Close mould
S2a
Introduce material into mould
S2b
Eject part from mould
S2c
S2
More parts?
Y
A
S3
N
End

Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/053118

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L51/56 B29C45/14 H01L23/29
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP H10 208875 A (HOKURIKU ELECT IND) 7 August 1998 (1998-08-07) abstract paragraph [0007] - paragraph [0018] figures 1-3	1-15
X	US 2004/219711 A1 (WU BI-CHU [TW] ET AL) 4 November 2004 (2004-11-04) paragraph [0033] - paragraph [0044]; figures 3,8	1,2,7-10
X	US 2007/117276 A1 (CHEN BEN W [US] ET AL CHEN BEN WEI [US] ET AL) 24 May 2007 (2007-05-24) paragraph [0026] - paragraph [0032]; figures 1A,4	1,8,10

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 January 2014	03/02/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bernabé Prieto, A

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/134488 A1 (YAMAZAKI SHUNPEI [JP] ET AL) 17 July 2003 (2003-07-17) figures 1,3	2,3
X	TEH N J ET AL: "Embedding of electronics within thermoplastic polymers using injection moulding technique", ELECTRONICS MANUFACTURING TECHNOLOGY SYMPOIUM, 2000. TWENTY-SIXTH IEEE /CPMT INTERNATIONAL OCTOBER 2-3, 2000, PISCATAWAY, NJ, USA,IEEE, 2 October 2000 (2000-10-02), pages 10-18, XP010535594, DOI: 10.1109/IEMT.2000.910703 ISBN: 978-0-7803-6482-0 figures 1-2	8

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2013/053118

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP H10208875 A	07-08-1998	NONE	
US 2004219711 A1	04-11-2004	TW 587061 B	11-05-2004
		US 2004219711 A1	04-11-2004
US 2007117276 A1	24-05-2007	CN 101641799 A	03-02-2010
		TW 200845323 A	16-11-2008
		US 2007117276 A1	24-05-2007
		US 2009283313 A1	19-11-2009
		WO 2008089415 A2	24-07-2008
US 2003134488 A1	17-07-2003	JP 2010135802 A	17-06-2010
		JP 2013062536 A	04-04-2013
		US 2003134488 A1	17-07-2003
		US 2005164470 A1	28-07-2005
		US 2006216909 A1	28-09-2006
		US 2009124062 A1	14-05-2009
		US 2011089811 A1	21-04-2011
		US 2013128199 A1	23-05-2013