

## **Collimating system for providing highly efficient parallel light**

The present invention relates to a collimating system. The invention provides a highly efficient parallel light system preferably for application in depth measurement or 3D imaging and sensing. The collimating system comprises at least one glass substrate and at least one polymer lens being present on at least one side of the substrate. The invention further relates to a component comprising the collimating system, at least one light source and at least one light source substrate. The invention also relates to a method of producing a collimating system and to the use of the collimating system, in particular for 3D imaging and sensing, distance measurement, depth measurement, face recognition, object recognition, animation, 3D Modeling, 3D scanning, mobile payment, finger print sensor, Augment Reality/Virtual Reality and/or facial beautification.

The principle of a collimating lens is shown in Figure 1. In the ideal collimator, the light source is put on the focal position  $S$ . The light image  $S'$  is at infinity. The light from the collimator is completely parallel. In reality, however, due to the tolerance that exist in each of the components, the light source cannot be located in the focal position completely. The light from the collimator is not completely parallel to each other. There is an aperture angle  $\theta$ . It is the angle between the light path and the optical axis. It can represent the parallelism of the light generated from a collimator lens. The smaller the aperture angle  $\theta$ , the more parallel light is generated by the collimating lens.

With the rapid growth of consumer electronics, especially smart phones, more and more optical applications have been in the focus of attention. Collimating lenses are widely used to provide parallel light for applications such as 3D imaging and sensing, face recognition and distance measurement. These lenses allow users to control the field of view, collection efficiency and spatial resolution of their setup, and to configure illumination and collection angles for sampling.

Consumer electronic products require low price, low-power and small size per element for their integration into current products. Wafer-level packaging (WLP) is a good solution when dealing with complex integrated circuits (IC) with a high number of input/output connections to the outside world. Integration of heterogeneous circuit functions — such as micro- and graphics-processing, field-programmable gate array (FPGA) logic, dynamic and static memory, radio-frequency (RF) and analog, and sensing and actuating — may also be needed at the package-level to be able to deliver complete systems.

WLP process is widely used for front camera production today. The individual optical components are stacked in combination with spacers and sometimes filters to create a single wafer

sized stack consisting of thousands of optics. These wafer level optics (WLO) are then stacked with the image sensor to create the camera. The dominant technology however is UV polymer replication on a transparent substrate.

The same manufacturing method is used for wafer level collimating lenses. However, there are limitations on the availability of the resins and substrates. A conventional WLO is manufactured using the same material for both lens and substrate to avoid a material conflict. In order to be suitable for the indicated applications, the collimating system should have good thermal conductivity, small size and excellent efficiency.

Previous publications have revealed the different structural parts within a collimating lens or wafer level packaging method or the optical design of how to achieve the recognition. But there is no disclosure regarding advantageous selection of the material of components.

WO 2017/176213 A1 shows WLP methods. However, a combination of a glass substrate and polymer lenses is not disclosed. Rather, substrates made of polymers are preferred. Glass may be present in substrates in combination with polymers in form of composite materials. However, wafers made of glass are suggested as carrier wafers only, i.e. as wafers being different from the actual substrates and not having any polymer lenses.

WO 2017/039535 A1 shows a manufacturing method of WLO. The optical element disclosed therein has a very different structure and is based on defined arrangement of two prisms. Furthermore, not even the combination of a glass substrate and polymer lenses is disclosed.

US 2017/0047362 A1 discloses that the thickness is very important on the whole light route and uses spacers to adjust the total thickness. However, a combination of a glass substrate and polymer lenses is not disclosed.

However, highly parallel light was not achieved so far, in particular not in applications that are associated with a comparably high thermal load as for example applications in which a vertical-cavity surface-emitting laser (VCSEL) or edge-emitting laser is used as a light source. Such laser will generate high temperature, in particular in case it produces high intensity and high contrast light. Thermal expansion effects lead to changes in the focal position so that the light coming from the lens is not sufficiently parallel to each other.

It is therefore an object of the present invention to overcome the disadvantages of the prior art. It is in particular an objection of the invention to provide a collimating system that is not expensive and nevertheless suitable for use in applications including VCSEL. It is also an object of the

invention to provide a collimating system that provides highly efficient parallel light. The collimating system should have a low temperature shift and low thermal deformation.

It turned out that in order to achieve this, it is advantageous to combine a glass substrate and a polymer lens. Moreover, it is of particular relevance that both the CTE and the thermal conductivity of glass and polymer are controlled with respect to each other. The thermal conductivities should in particular be chosen such that temperature shifts are reduced. The CTEs should in particular be chosen such that the influence of a temperature shift on the optical performance is reduced so that highly parallel light is provided by the collimating system even under such conditions.

The collimating system may for example be used for the technical solutions of TOF (time-of-flight), structure light and stereo vision.

The objects are solved by the subject-matter of the patent claims. The objects are in particular solved by a collimating system comprising at least one glass substrate and at least one polymer lens being present on at least one side of the substrate, wherein the collimating system has an aperture angle  $\theta$  of less than  $15^\circ$ , wherein the ratio of the CTE of the polymer (in the temperature range 30 to  $40^\circ\text{C}$ ) and the CTE of the glass (in the temperature range 30 to  $40^\circ\text{C}$ ) is at most 40, and wherein the difference between the thermal conductivity of the glass (at a temperature of  $89^\circ\text{C}$ ) and the thermal conductivity of the polymer (at a temperature of  $89^\circ\text{C}$ ) is at most  $1.1 \text{ W}/(\text{m}\cdot\text{K})$ .

The collimating system of the invention comprises at least one glass substrate and at least one polymer lens being present on at least one side of the substrate. Preferably, the polymer lenses adhere directly to the glass substrate. In other words, it is preferred that there are no adhesive layers or intermediate layers between the polymer lenses and the glass substrate. However, in certain embodiments there may be one or more intermediate layers between the glass substrate and the polymer lenses.

The polymer lens comprises a polymer material, preferably in amounts of at least 90% by weight, more preferably at least 95% by weight, more preferably at least 98% by weight, more preferably at least 99% by weight. Preferably, the polymer lens essentially consists of a polymer material. Thus, other components are present at most as impurities in amounts of not more than 0.1 % by weight. In particular, the polymer lens is not a composite material comprising other materials in amounts of more than 0.1 % by weight.

Preferably, the glass substrate essentially consists of glass. Thus, other components are preferably present at most as impurities in amounts of not more than 0.1 % by weight. In particular,

the glass substrate is preferably not a composite material comprising other materials than glass in amounts of more than 0.1 % by weight. In some embodiments, a coating, in particular a Cr coating may be applied to the glass substrate in the areas of the substrate that do not have the lenses. Such coating may be advantageous for reducing stray light.

The collimating system has an aperture angle  $\theta$  of less than  $15^\circ$ , preferably less than  $10^\circ$ , more preferably less than  $5^\circ$ , more preferably less than  $2^\circ$ , more preferably less than  $1^\circ$ , more preferably less than  $0.5^\circ$ , more preferably less than  $0.1^\circ$ , more preferably less than  $0.01^\circ$ .

The present invention shows a solution to the prior art problems based on the combination of a glass substrate and at least one polymer lens. A polymer lens can be imprinted on a glass substrate and it is easy to be molded. Glass is a low CTE material compared to polymer material. It has a low temperature shift. Meanwhile, glass has advantages on the anti-deformation properties compared to polymer. Glass has large hardness and temperature resistance.

However, combining a glass substrate and a polymer lens for a collimating system is not trivial at all. Importantly, it has to be kept in mind that the material selection has to be done such that focal length and light intensity are not compromised. In particular, highly parallel light should be provided by the collimating system even in applications including VCSEL that are associated with increased temperatures. The present inventors have found a solution by combining a glass substrate and a polymer lens in a collimating system. Notably, the glasses for the glass substrate have to be chosen with great care. The following influence factors turned out to be particularly relevant for obtaining a collimating system having excellent properties, in particular producing highly parallel light.

As described above, the substrate of a collimating system may be confronted with a tremendous amount of heat, in particular generated in applications including VCSEL. Therefore, it is advantageous if the substrate material has a high thermal conductivity. From material view, metal has the best thermal conductivity. But it is not transparent. Glass is a good thermal conductivity material in transparent group. Glass has much better thermal conductivity than polymer. It will reduce the temperature shift more efficiently than polymer. Importantly, the collimating system of the present invention comprises a glass substrate. Furthermore, the collimating system of the invention may comprise one or more spacers, preferably glass spacers. A spacer, in particular a glass spacer, is particularly useful in embodiments in which the collimating system comprises more than one glass substrate, for example two glass substrates. A spacer, in particular a glass spacer, is preferably located between two glass substrates. This enables spacing the two glass substrates from each other and locating them in a defined distance from each other in the collimating system. Preferably, the spacer is a glass spacer. Preferably the

glass spacer has the same glass composition as the glass substrates. This is advantageously from an optical point of view and furthermore in order to minimize potential mechanical stresses in the collimating system, for example arising from different expansion properties under heat load. Therefore, if glass properties or glass compositional features are described herein, this preferably refers to the glass of the glass substrate and to the glass of the optionally present glass spacer. Furthermore, if the present description refers to the "*polymer*", this refers to the polymer of the polymer lens unless indicated otherwise. The material of the spacer is preferably selected from the group consisting of glass, polymer, ceramic and metal. More preferably, the spacer is a glass spacer.

Preferably, the thermal conductivity of the glass at a temperature of 89°C is in the range of from 0.7 to 1.4 W/(m\*K), more preferred from 0.75 to 1.3 W/(m\*K), more preferably from 0.85 to 1.25 W/(m\*K), more preferably from 1.0 to 1.2 W/(m\*K).

Preferably, the thermal conductivity of the polymer at a temperature of 89°C is in the range of from 0.05 to 0.6 W/(m\*K), more preferred from 0.1 to 0.5 W/(m\*K), more preferably from 0.15 to 0.4 W/(m\*K), more preferably from 0.2 to 0.3 W/(m\*K).

The thermal conductivity is preferably determined according to ISO 22007-2:2015(E).

It is advantageous if the difference between the thermal conductivity of the glass and the thermal conductivity of the polymer is not extremely large. This is in particular advantageous for providing highly parallel light even under increased heat load. The difference between the thermal conductivity of the glass at a temperature of 89°C and the thermal conductivity of the polymer at a temperature of 89°C is at most 1.1 W/(m\*K), preferably at most 1.0 W/(m\*K), more preferred at most 0.95 W/(m\*K), more preferred at most 0.9 W/(m\*K), more preferred at most 0.85 W/(m\*K).

Furthermore, it is advantageous if the CTE (temperature range 30 to 40°C) of the glass is comparably low. Importantly, the lower the CTE, the lower the changes in thickness and refractive index upon heat impact. Thus, a lower CTE is also associated with smaller changes of the focal position upon heat impact as compared to a higher CTE. Preferably, the CTE (in the temperature range 30 to 40°C) of the glass is at most 15 ppm/K, more preferred at most 12 ppm/K, more preferred at most 10 ppm/K.

It also advantageous if the CTE (temperature range 30 to 40°C) of the polymer is not too large in order to avoid larger changes of the material properties due to temperature change. However, suitable polymers generally have a CTE that is substantially larger as compared to the CTE of

the glass of the invention. Preferably, the CTE (in the temperature range 30 to 40°C) of the polymer is smaller than 200 ppm/K, more preferably smaller than 150 ppm/K.

The CTE, in particular the CTE of glass, is preferably determined according to ISO 7991 : 1987 (E). The CTE, in particular the CTE of the polymer, may also be determined according to ISO 11359-2:1999(en). Further suitable options for determining the CTE are known to the skilled person.

A small CTE of the polymer is also advantageous for another reason. In fact, it is advantageous if the difference of the CTE of the polymer and the CTE of the glass is comparably low. In other words, the ratio of the CTE of the polymer and the CTE of the glass should not exceed certain values. This will reduce the stress caused by temperature changes after assembly of glass substrate and polymer lens. Notably, a high stress will increase the crack ratio in later dicing process. Furthermore, a low difference of the CTE of the polymer and the CTE of the glass is also advantageous for provision of highly parallel light even under increased heat load. The ratio of the CTE of the polymer (in the temperature range 30 to 40°C) and the CTE of the glass (in the temperature range 30 to 40°C) is at most 40, preferably at most 30, more preferably at most 25, more preferably at most 20, more preferably at most 15, more preferably at most 10.

The size of the whole collimating system is very important, especially in consumer electronics. The market tendency is that thinner is better. Notably, glass is a good material to provide enough strength as a substrate with thinner thickness. Preferably, the thickness of the glass substrate is in the range of from 30  $\mu\text{m}$  to 1000  $\mu\text{m}$ , more preferred from 50  $\mu\text{m}$  to 800  $\mu\text{m}$ , more preferred from 70  $\mu\text{m}$  to 700  $\mu\text{m}$ , more preferred from 100  $\mu\text{m}$  to 600  $\mu\text{m}$ . In some preferred embodiments, the thickness of the glass substrate is at most 400  $\mu\text{m}$ , more preferably at most 300  $\mu\text{m}$ , more preferably at most 250  $\mu\text{m}$ , more preferably at most 200  $\mu\text{m}$ .

Preferably, the thickness of the spacer, in particular the glass spacer, is in the range of from 45  $\mu\text{m}$  to 1000  $\mu\text{m}$ , more preferred from 75  $\mu\text{m}$  to 1000  $\mu\text{m}$ , more preferred from 100  $\mu\text{m}$  to 1000  $\mu\text{m}$ . Preferably, the thickness of the spacer, in particular the glass spacer, is chosen such that the glass substrates are spaced from each other by such a distance that a polymer lens potentially being present on a side of a substrate that faces the other substrate is neither in direct physical contact with the other substrate nor with a polymer lens potentially located thereon.

It is also advantageous if the glass has a low thickness variation, in particular a low Local Thickness Variation (LTV) and/or a low Total Thickness Variation (TTV). The thickness variation of glass substrate and/or spacer, in particular glass spacer, also influence the focal position so that larger variations are associated with a larger aperture angle  $\theta$  and thus with less parallel light.

LTV is the difference between the highest point and the lowest point within one side of the surface of a substrate and/or spacer. Thus, LTV describes the local thickness fluctuation that is characteristic for the surface quality on a surface. Preferably, LTV of the glass substrate and/or spacer, in particular glass spacer, over a surface of  $25 \text{ mm}^2$  is smaller than  $5 \text{ }\mu\text{m}$ , more preferably smaller than  $2 \text{ }\mu\text{m}$ .

The TTV (Total Thickness Variation) is understood to be the difference between the highest and the lowest protrusion on the surface of a glass substrate and/or spacer relative to its sides. Thus, TTV describes the thickness variation inside the glass substrate and/or spacer. Preferably, TTV of the glass substrate and/or the spacer, in particular the glass spacer, is smaller than  $40 \text{ }\mu\text{m}$ , more preferred smaller than  $30 \text{ }\mu\text{m}$ , more preferred smaller than  $20 \text{ }\mu\text{m}$ , more preferred smaller than  $16 \text{ }\mu\text{m}$ , more preferred smaller than  $14 \text{ }\mu\text{m}$ , more preferred smaller than  $12 \text{ }\mu\text{m}$ , more preferred smaller than  $10 \text{ }\mu\text{m}$ , more preferred smaller than  $8 \text{ }\mu\text{m}$ , more preferred smaller than  $6 \text{ }\mu\text{m}$ , more preferred smaller than  $4 \text{ }\mu\text{m}$ . Preferably, TTV is determined according to SEMI MF 1530GBIR.

Another important aspect is the refractive index  $n_d$ . Large refractive index  $n_d$  could reduce the total packing size but it is difficult to get a high refractive index  $n_d$  for polymer lens material. Preferably, the polymer of the polymer lens has a refractive index  $n_d$  in a range of from 1.40 to 1.60, more preferably from 1.42 to 1.58, more preferably from 1.44 to 1.56, more preferably from 1.45 to 1.55, more preferably from 1.46 to 1.54.

Preferably, the glass has a refractive index  $n_d$  in a range of from 1.45 to 1.90, more preferably from 1.46 to 1.80, more preferably from 1.47 to 1.70, more preferably from 1.48 to 1.65, more preferably from 1.49 to 1.60, more preferably from 1.50 to 1.54.

Particularly good optical performance is achieved by low differences of the refractive index of glass and polymer material. Otherwise, the light loss on the boundary between the two materials weakens the light intensity, which will compromise the imaging quality in application. Moreover, low respective differences are also advantageous for achieving highly parallel light. Preferably, the refractive index  $n_d$  of the glass differs from the refractive index  $n_d$  of the polymer by less than 0.5, more preferably less than 0.4, more preferably less than 0.3, more preferably less than 0.2, more preferably less than 0.1, more preferably less than 0.06, more preferably less than 0.05, more preferably less than 0.04, more preferably less than 0.03, more preferably less than 0.02, more preferably less than 0.01.

Another important aspect is the bonding strength between glass substrate and polymer lens. In particular, the polymer lens should adhere to the glass substrate well during the life time of the

collimating system. The bonding strength may for example be increased by choosing advantageous glass surface properties, in particular those that increase wetting of the glass by the polymer. Preferably, the glass of the invention has a surface roughness  $R_a < 1 \text{ nm}$ .

Preferably, a contact angle  $< 25^\circ$  is achieved between the glass substrate and the polymer lens, in particular on a cleaned surface between the glass substrate and the polymer lens.

According to certain aspects of the invention, the glass of the glass substrate may be cut, diced, coated, chemically toughened, etched and/or structured.

Preferably, the glass substrate and the polymer lens of the invention have a transmittance  $> 90\%$ , in particular in the wavelength range of from 380 nm to 1200 nm so that particularly good optical properties are achieved. The term "*transmittance*" as used in the present description refers to the total transmittance, thus to the percentage of light intensity behind the glass substrate and/or the polymer lens as compared to the light intensity that was initially applied.

Preferably, the glass is selected from the group consisting of silicate glasses (in particular soda-lime glasses), borosilicate glasses, aluminosilicate glasses and aluminoborosilicate glasses. Borosilicate glasses, aluminosilicate glasses and soda-lime glasses are particularly preferred.

In preferred embodiments of the present invention, the glass preferably comprises the following components in the indicated ranges in % by weight:

| Component                                                        | % by weight |
|------------------------------------------------------------------|-------------|
| $\text{SiO}_2$                                                   | 63-85       |
| $\text{Al}_2\text{O}_3$                                          | 0-10        |
| $\text{B}_2\text{O}_3$                                           | 5-20        |
| $\text{Li}_2\text{O} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ | 2-14        |
| $\text{MgO} + \text{CaO} + \text{SrO} + \text{BaO} + \text{ZnO}$ | 0-12        |
| $\text{TiO}_2 + \text{ZrO}_2$                                    | 0-5         |
| $\text{P}_2\text{O}_5$                                           | 0-2         |

In preferred embodiments of the present invention, the glass preferably comprises the following components in the indicated ranges in % by weight:

| Component                                                | % by weight |
|----------------------------------------------------------|-------------|
| SiO <sub>2</sub>                                         | 60-84       |
| Al <sub>2</sub> O <sub>3</sub>                           | 0-10        |
| B <sub>2</sub> O <sub>3</sub>                            | 3-18        |
| Li <sub>2</sub> O + Na <sub>2</sub> O + K <sub>2</sub> O | 5-20        |
| MgO + CaO + SrO + BaO + ZnO                              | 0-15        |
| TiO <sub>2</sub> + ZrO <sub>2</sub>                      | 0-4         |
| P <sub>2</sub> O <sub>5</sub>                            | 0-2         |

In preferred embodiments of the present invention, the glass preferably comprises the following components in the indicated ranges in % by weight:

| Component                      | % by weight |
|--------------------------------|-------------|
| SiO <sub>2</sub>               | 58-65       |
| Al <sub>2</sub> O <sub>3</sub> | 14-25       |
| B <sub>2</sub> O <sub>3</sub>  | 6-10.5      |
| MgO + CaO + SrO + BaO + ZnO    | 8-18        |
| ZnO                            | 0-2         |

In preferred embodiments of the present invention, the glass preferably comprises the following components in the indicated ranges in % by weight:

| Component                      | % by weight |
|--------------------------------|-------------|
| SiO <sub>2</sub>               | 50-81       |
| Al <sub>2</sub> O <sub>3</sub> | 0-5         |

| Component                                                | % by weight |
|----------------------------------------------------------|-------------|
| B <sub>2</sub> O <sub>3</sub>                            | 0-5         |
| Li <sub>2</sub> O + Na <sub>2</sub> O + K <sub>2</sub> O | 5-28        |
| MgO + CaO + SrO + BaO + ZnO                              | 5-25        |
| TiO <sub>2</sub> + ZrO <sub>2</sub>                      | 0-6         |
| P <sub>2</sub> O <sub>5</sub>                            | 0-2         |

In preferred embodiments of the present invention, the glass preferably comprises the following components in the indicated ranges in % by weight:

| Component                                                | % by weight |
|----------------------------------------------------------|-------------|
| SiO <sub>2</sub>                                         | 52-66       |
| B <sub>2</sub> O <sub>3</sub>                            | 0-8         |
| Al <sub>2</sub> O <sub>3</sub>                           | 15-25       |
| MgO + CaO + SrO + BaO + ZnO                              | 0-6         |
| ZrO <sub>2</sub>                                         | 0-2.5       |
| Li <sub>2</sub> O + Na <sub>2</sub> O + K <sub>2</sub> O | 4-30        |
| TiO <sub>2</sub> + CeO <sub>2</sub>                      | 0-2.5       |

In the above described glass compositions, As<sub>2</sub>O<sub>3</sub>, Sb<sub>2</sub>O<sub>3</sub>, SnO<sub>2</sub>, SO<sub>3</sub>, Cl, F and/or CeO<sub>2</sub> may be used as refining agents in amounts of from 0 to 2 % by weight.

Preferably, the polymer of the polymer lens is a resin, preferably selected from the group consisting of epoxy resins and acrylic resins. Epoxy resins are particularly preferred. Particularly preferred polymers are epoxy resins selected from the group consisting of DELO KATIOBOND OM614, DELO KATIOBOND AD VE 18499 and DELO KATIOBOND OM VE 110021. Such epoxy resins are provided by DELO Industrial Adhesives (Windach, Germany).

As described above, the present invention relates to a collimating system comprising at least one glass substrate and at least one polymer lens being present on at least one side of the substrate.

The glass substrate of the invention has preferably the form of a sheet or disk or plate. In other words, length and width of the substrate are preferably substantially larger as compared to its thickness, or, in case of a circular basal area the diameter is substantially larger as compared to the thickness of the substrate. The term "*substantially larger*" preferably means that length and width or diameter of the substrate are larger as compared to its thickness by a factor of at least 5, more preferably at least 10, more preferably at least 20, more preferably at least 30, more preferably at least 40, more preferably at least 50. Such sheet-like substrates have two main surfaces that may also be termed "*sides*" of the substrate. Thus, such substrates have two sides.

Preferably, polymer lenses are located on both sides of the substrate. More preferably, the number of polymer lenses is equal on each of the two sides of the glass substrate. Preferably, the polymer lenses are located such that each lens on one side of the substrate has a corresponding lens on the other side of the substrate. Preferably, corresponding lenses are lenses that are essentially aligned to each other. In other words, corresponding lenses are preferably lenses on opposing sides of the substrate that have the same optical axis or optical axes deviating from each other by at most 10%, more preferably at most 5%, more preferably at most 2%, more preferably at most 1% of the diameter of the lens on the surface of the substrate.

The total number of polymer lenses in the collimating system is at least 1, preferably at least 2, more preferably at least 3, more preferably at least 4, more preferably at least 6 polymer lenses. Preferably, the total number of polymer lenses on one side of the substrate is at least 1, preferably at least 2, more preferably at least 3, more preferably at least 4, more preferably at least 6, more preferably at least 10, more preferably at least 20, more preferably at least 30, more preferably at least 40, more preferably at least 50. Preferably, the total number of polymer lenses on each of the two sides of the substrate is at least 1, preferably at least 2, more preferably at least 3, more preferably at least 4, more preferably at least 6, more preferably at least 10, more preferably at least 20, more preferably at least 30, more preferably at least 40, more preferably at least 50.

Preferably, the collimating system comprises two glass substrates. Preferably, the two glass substrates are spaced by a spacer, in particular by a glass spacer. Preferably, the glass spacer has the same glass composition as the glass substrates. Preferably, the spacer, in particular the

glass spacer, has holes at the positions of the polymer lenses being present on the glass substrates spaced by the spacer, in particular the glass spacer. Such holes are advantageous as they avoid the spacer, in particular the glass spacer, coming into physical contact with the polymer lenses.

In certain embodiments, the collimating system may further comprise at least one light guide. A light guide may be advantageous for changing the optical route.

The present invention also relates to a component comprising the collimating system of the invention and further comprising at least one light source, preferably laser light source, more preferably vertical-cavity surface-emitting laser (VCSEL) and at least one light source substrate, preferably laser light source substrate, more preferably VCSEL substrate, wherein the light source, preferably laser light source, more preferably VCSEL is located on one side of the light source substrate, preferably laser light source substrate, more preferably VCSEL substrate. Preferably, the laser light source substrate, preferably laser light source substrate, more preferably VCSEL substrate is connected to one glass substrate of the collimating system via an adhesive. The component may also be referred to as optical component. Preferably, the maximum emission wavelength of the light source, preferably laser light source, more preferably VCSEL is in the range of from 700 nm to 1200 nm, more preferred from 700 nm to 1000 nm, more preferred from 800 nm to 1000 nm, more preferred from 825 nm to 950 nm. Particularly preferred light sources, preferably laser light source, more preferably VCSELs maximally emit in the range of 840 to 860 nm or in the range of 930 to 950 nm. Light sources, preferably laser light sources, more preferably VCSELs maximally emitting at 840 to 860 nm are particularly useful for face/object recognition, in particular for detecting face(s) or person(s). Light sources, preferably laser light sources, more preferably VCSELs maximally emitting at 930 to 950 nm may be useful for reducing the influence of environmental light.

The present invention also relates to a method of producing a collimating system of the invention, the method comprising the following steps:

- a) Providing at least one glass substrate,
- b) Positioning at least one polymer lens onto at least one side of the substrate.

Preferably, the step of positioning the polymer lens onto the substrate comprises the following steps:

- b1) Dropping liquid polymer resin onto the substrate at pre-defined positions,

b2) Curing the polymer resin.

Preferably, the polymer resin is cured with UV light or thermally. More preferably, the polymer resin is cured with UV light.

The present invention also relates to the use of a collimating system of the invention for 3D imaging and sensing, distance measurement, depth measurement, face recognition, object recognition, animation, 3D Modeling, 3D scanning, mobile payment, finger print sensor, Augment Reality/Virtual Reality and/or facial beautification.

### Brief description of the Figures

Figure 1 schematically shows the principle of a collimating lens 102 (indicated as vertical Up Down Arrow). A light emitter 101 (indicated as circle) is present in the focal position S of the collimating lens 102. The position of the light image is indicated by S'. The aperture angle  $\theta$  is shown as the angle between the light path (indicated as arrow) and the optical axis (indicated by the dashed horizontal line) and it can represent the parallelism of the light generated from the collimator lens 102.

Figure 2 schematically shows a top view of a microlens array 201. A plurality of polymer lenses 203 are located on a round-shaped glass substrate 202.

Figure 3 schematically shows a cross-section of a part of a component comprising a collimating system of the invention. The collimating system may comprise a plurality of polymer lenses as shown in Figure 2. However, Figure 3 shows only one such polymer lens 1 for better comprehensibility. The polymer lens 1 is located on the upper side of the glass substrate 11. The lower side of the glass substrate 11 is connected to the upper side of a VCSEL (vertical-cavity surface-emitting laser) substrate 21 via an adhesive 23. The component further comprises a VCSEL 22 being located on the upper side of the VCSEL substrate 21.

Figure 4 schematically shows a cross-section of a part of a component comprising a collimating system of the invention. The collimating system of Figure 4 differs from the collimating system of Figure 3 in that the collimating system of Figure 4 comprises one polymer lens 2 on the upper side of the glass substrate 11 and one additional polymer lens 1 on the lower side of the glass substrate 11. The polymer lens 2 and the polymer lens 1 are aligned to each other. Polymer lens 2 and polymer lens 1 have the same optical axis (optical axis not shown). The lower side of the glass substrate 11 is connected to the upper side of a VCSEL substrate 21 via an adhesive 23. The component further comprises a VCSEL 22 being located on the upper side of the VCSEL substrate 21.

Figure 5 schematically shows a cross-section of a part of a component comprising a collimating system of the invention. The collimating system of Figure 5 comprises two glass substrates 11, 12. Polymer lens 4 is located on the upper side of the upper glass substrate 12. Polymer lens 3 is located on the lower side of the upper glass substrate 12. Polymer lens 2 is located on the upper side of the lower glass substrate 11. Polymer lens 1 is located on the lower side of the lower glass substrate 11. The polymer lenses are aligned to each other and have the same optical axis (optical axis not shown). The lower side of the lower glass substrate 11 is connected to the upper side of a VCSEL substrate 21 via an adhesive 23. The component further comprises a VCSEL 22 being located on the upper side of the VCSEL substrate 21. The upper glass substrate 12 and the lower glass substrate 11 are spaced by a spacer 24, in particular by a glass spacer 24. The spacer 24, in particular the glass spacer 24, comprises a recess for accommodating polymer lenses 3 and 2. The thickness of the spacer 24, in particular the glass spacer 24, is chosen such that glass substrates 12 and 11 are spaced from each other by such a distance that polymer lenses 3 and 2 are not in direct physical contact with each other. Lenses 3 and 2 as shown in Figure 5 have a matched curve shape. This can help reducing chromatic aberrations.

## Examples

### **Example 1**

A collimating module as shown in Figure 3 is simulated with following material selection:

Glass substrate having the following composition (Glass 1):

| <b>Component</b>               | <b>% by weight</b> |
|--------------------------------|--------------------|
| SiO <sub>2</sub>               | 64                 |
| B <sub>2</sub> O <sub>3</sub>  | 8                  |
| Al <sub>2</sub> O <sub>3</sub> | 4                  |
| Na <sub>2</sub> O              | 6                  |
| K <sub>2</sub> O               | 7                  |
| ZnO                            | 6                  |
| TiO <sub>2</sub>               | 4                  |

Polymer lens material: DELO OM614

Operation temperature 25°C to 60°C

Incident light wavelength: 940 nm

Original lens size: chord length 2 mm and 0.2 mm height

| Material | CTE               | Refractive index | Thickness tolerance |
|----------|-------------------|------------------|---------------------|
| Glass 1  | 7.2 ppm (30-40°C) | 1.5137           | ±10 µm              |
| OM614    | 86 ppm (30-40°C)  | 1.5063           | ±2 µm               |

Simulation results:

Aperture angle  $\theta=0.00156^\circ$

Thus, a very low aperture angle is achieved with the combination of Glass 1 and OM614 polymer lens.

## Example 2

A collimating module as shown in Figure 3 is simulated with following material selection:

Glass substrate having the following composition (Glass 2):

| Component                      | % by weight |
|--------------------------------|-------------|
| SiO <sub>2</sub>               | 61          |
| B <sub>2</sub> O <sub>3</sub>  | 11          |
| Al <sub>2</sub> O <sub>3</sub> | 18          |
| MgO                            | 3           |
| CaO                            | 4           |
| BaO                            | 3           |

Polymer lens material: DELO OM614

Operation temperature 25°C to 60°C

Incident light wavelength: 940 nm

Original lens size: chord length 2 mm and 0.2 mm height

| Material | CTE               | Refractive index | Thickness tolerance |
|----------|-------------------|------------------|---------------------|
| Glass 2  | 3.2 ppm (30-40°C) | 1.503            | ±10 µm              |
| OM614    | 86 ppm (30-40°C)  | 1.5063           | ±2 µm               |

Simulation results:

Aperture angle  $\theta=0.00164^\circ$

Thus, a very low aperture angle is achieved with the combination of Glass 2 and OM614 polymer lens.

### Example 3

A collimating module as shown in Figure 3 is simulated with following material selection:

Glass substrate having the following composition (Glass 3):

| Component                     | % by weight |
|-------------------------------|-------------|
| SiO <sub>2</sub>              | 70          |
| B <sub>2</sub> O <sub>3</sub> | 0.1         |
| Na <sub>2</sub> O             | 10          |
| K <sub>2</sub> O              | 8           |
| ZnO                           | 4           |
| CaO                           | 6           |
| BaO                           | 2.5         |

Polymer lens material: DELO OM614

Operation temperature 25°C to 60°C

Incident light wavelength: 940 nm

Original lens size: chord length 2 mm and 0.2 mm height

| <b>Material</b> | <b>CTE</b>       | <b>Refractive index</b> | <b>Thickness tolerance</b> |
|-----------------|------------------|-------------------------|----------------------------|
| Glass 3         | 12 ppm (30-40°C) | 1.5231                  | ±10 µm                     |
| OM614           | 86 ppm (30-40°C) | 1.5063                  | ±2 µm                      |

Simulation results:

Aperture angle  $\theta=0.00257^\circ$

Thus, a very low aperture angle is achieved with the combination of Glass 3 and OM614 polymer lens.

### List of Reference Signs

- 1 Polymer lens
- 2 Polymer lens
- 3 Polymer lens
- 4 Polymer lens
- 11 Glass substrate
- 12 Glas substrate
- 21 Light source substrate, in particular VCSEL (vertical-cavity surface-emitting laser) substrate
- 22 Light source, in particular VCSEL
- 23 Adhesive
- 24 Spacer, in particular glass spacer
- 101 Light emitter

102 Collimating lens

201 Microlens array

202 Glass substrate

203 Polymer lenses

## **Claims**

1. Collimating system comprising at least one glass substrate (11, 12) and at least one polymer lens (1, 2, 3, 4) being present on at least one side of the substrate (11, 12), wherein the collimating system has an aperture angle  $\theta$  of less than  $1^\circ$ , wherein a ratio of a coefficient of thermal expansion (CTE) of the polymer and the CTE of the glass is at most 30, and wherein a difference between the thermal conductivity of the glass and the thermal conductivity of the polymer is at most  $1.0 \text{ W/(m}^\circ\text{K)}$ .
2. Collimating system according to claim 1, wherein a total number of polymer lenses (1, 2, 3, 4) is at least 2.
3. Collimating system according to claim 2, wherein the polymer lenses (1, 2, 3, 4) are distributed over a side of the substrate (11, 12) based on a regular grid.
4. Collimating system according to at least one of the preceding claims, wherein polymer lenses (1, 2, 3, 4) are present on both sides of the substrate (11, 12).
5. Collimating system according to at least one of the preceding claims, wherein the polymer lens (1, 2, 3, 4) consists of a polymer selected from a group consisting of epoxy resins and acrylic resins.
6. Collimating system according to at least one of the preceding claims, wherein the glass is selected from a group consisting of silicate glasses, borosilicate glasses, aluminosilicate glasses and aluminoborosilicate glasses.
7. Collimating system according to at least one of the preceding claims, wherein the glass comprises following components in the indicated ranges in % by weight:

| Component                                                        | % by weight |
|------------------------------------------------------------------|-------------|
| $\text{SiO}_2$                                                   | 63-85       |
| $\text{Al}_2\text{O}_3$                                          | 0-10        |
| $\text{B}_2\text{O}_3$                                           | 5-20        |
| $\text{Li}_2\text{O} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ | 2-14        |
| $\text{MgO} + \text{CaO} + \text{SrO} + \text{BaO} + \text{ZnO}$ | 0-12        |

| Component                     | % by weight |
|-------------------------------|-------------|
| $\text{TiO}_2 + \text{ZrO}_2$ | 0-5         |
| $\text{P}_2\text{O}_5$        | 0-2         |

8. Collimating system according to at least one of the preceding claims, wherein the glass comprises following components in the indicated ranges in % by weight:

| Component                                                        | % by weight |
|------------------------------------------------------------------|-------------|
| $\text{SiO}_2$                                                   | 60-84       |
| $\text{Al}_2\text{O}_3$                                          | 0-10        |
| $\text{B}_2\text{O}_3$                                           | 3-18        |
| $\text{Li}_2\text{O} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ | 5-20        |
| $\text{MgO} + \text{CaO} + \text{SrO} + \text{BaO} + \text{ZnO}$ | 0-15        |
| $\text{TiO}_2 + \text{ZrO}_2$                                    | 0-4         |
| $\text{P}_2\text{O}_5$                                           | 0-2         |

9. Collimating system according to at least one of claims 1 to 6, wherein the glass comprises following components in the indicated ranges in % by weight:

| Component                                                        | % by weight |
|------------------------------------------------------------------|-------------|
| $\text{SiO}_2$                                                   | 58-65       |
| $\text{Al}_2\text{O}_3$                                          | 14-25       |
| $\text{B}_2\text{O}_3$                                           | 6-10.5      |
| $\text{MgO} + \text{CaO} + \text{SrO} + \text{BaO} + \text{ZnO}$ | 8-18        |
| $\text{ZnO}$                                                     | 0-2         |

10. Collimating system according to at least one of claims 1 to 8, wherein the glass comprises following components in the indicated ranges in % by weight:

| Component                                                | % by weight |
|----------------------------------------------------------|-------------|
| SiO <sub>2</sub>                                         | 50-81       |
| Al <sub>2</sub> O <sub>3</sub>                           | 0-5         |
| B <sub>2</sub> O <sub>3</sub>                            | 0-5         |
| Li <sub>2</sub> O + Na <sub>2</sub> O + K <sub>2</sub> O | 5-28        |
| MgO + CaO + SrO + BaO + ZnO                              | 5-25        |
| TiO <sub>2</sub> + ZrO <sub>2</sub>                      | 0-6         |
| P <sub>2</sub> O <sub>5</sub>                            | 0-2         |

11. Collimating system according to at least one of claims 1 to 6, wherein the glass comprises following components in the indicated ranges in % by weight:

| Component                                                | % by weight |
|----------------------------------------------------------|-------------|
| SiO <sub>2</sub>                                         | 52-66       |
| B <sub>2</sub> O <sub>3</sub>                            | 0-8         |
| Al <sub>2</sub> O <sub>3</sub>                           | 15-25       |
| MgO + CaO + SrO + BaO + ZnO                              | 0-6         |
| ZrO <sub>2</sub>                                         | 0-2.5       |
| Li <sub>2</sub> O + Na <sub>2</sub> O + K <sub>2</sub> O | 4-30        |
| TiO <sub>2</sub> + CeO <sub>2</sub>                      | 0-2.5       |

12. Collimating system according to at least one of the preceding claims, wherein the collimating system comprises two glass substrates (11, 12).
13. Collimating system according to claim 12, wherein the two glass substrates (11, 12) are spaced by a glass spacer (24).

14. Collimating system according to claim 13, wherein the glass spacer (24) has same glass composition as the glass substrates (11, 12).
15. Collimating system according to at least one of the preceding claims, wherein a number of polymer lenses (1, 2, 3, 4) is equal on each of the two sides of the glass substrate (11, 12).
16. Collimating system according to claim 15, wherein the polymer lenses (1, 2, 3, 4) are located such that each lens (1, 2, 3, 4) on one side of the substrate (11, 12) has a corresponding lens (1, 2, 3, 4) on the other side of the substrate (11, 12).
17. Collimating system according to at least one of the preceding claims, wherein the collimating system has an aperture angle  $\theta$  of less than  $0.5^\circ$ .
18. Collimating system according to at least one of the preceding claims, wherein the thermal conductivity of the glass is in the range of from 0.7 to 1.4 W/(m\*K).
19. Collimating system according to at least one of the preceding claims, wherein the thermal conductivity of the polymer is in the range of from 0.05 to 0.6 W/(m\*K).
20. Collimating system according to at least one of the preceding claims, wherein the difference between the thermal conductivity of the glass and the thermal conductivity of the polymer is at most 0.85 W/(m\*K).
21. Collimating system according to at least one of the preceding claims, wherein the CTE of the glass is at most 15 ppm/K.
22. Collimating system according to at least one of the preceding claims, wherein the CTE of the polymer is smaller than 200 ppm/K.
23. Collimating system according to at least one of the preceding claims, wherein the ratio of the CTE of the polymer and the CTE of the glass is at most 25.
24. Collimating system according to at least one of the preceding claims, wherein a thickness of the glass substrate (11, 12) is in the range of from 30  $\mu\text{m}$  to 1000  $\mu\text{m}$ .
25. Collimating system according to at least one of claims 8 to 19, wherein a thickness of the glass spacer (24) is in the range of from 45  $\mu\text{m}$  to 1000  $\mu\text{m}$ .

26. Collimating system according to at least one of the preceding claims, wherein a Local Thickness Variation LTV of the glass substrate (11, 12) and/or glass spacer (24) over a surface of 25 mm<sup>2</sup> is smaller than 5 µm.
27. Collimating system according to at least one of the preceding claims, wherein a Total Thickness Variation TTV of the glass substrate (11, 12) and/or glass spacer (24) is smaller than 40 µm.
28. Collimating system according to at least one of the preceding claims, wherein the polymer of the polymer lens (1, 2, 3, 4) has a refractive index  $n_d$  in a range of from 1.40 to 1.60.
29. Collimating system according to at least one of the preceding claims, wherein the glass has a refractive index  $n_d$  in a range of from 1.45 to 1.90.
30. Collimating system according to at least one of the preceding claims, wherein a refractive index  $n_d$  of the glass differs from a refractive index  $n_d$  of the polymer by less than 0.5.
31. Component comprising the collimating system according to at least one of the preceding claims, wherein the component further comprises at least one light source (22) and at least one light source substrate (21), wherein the light source (22) is located on one side of the light source substrate (21).
32. Component according to claim 31, wherein the light source substrate (21) is connected to one glass substrate (11, 12) of the collimating system via an adhesive (23).
33. Component according to claim 31 or 32, wherein a maximum emission wavelength of the light source (22) is in the range of from 700 nm to 1000 nm.
34. Component according to at least one of claims 31 to 33, wherein the light source (22) is a laser light source (22) and wherein the light source substrate (21) is a laser light source substrate (21).
35. Component according to at least one claims 31 to 34, wherein the light source (22) or the laser light source (22) is a vertical-cavity surface-emitting laser (VCSEL) (22) and wherein the light source substrate (21) or the laser light source substrate (21) is a VCSEL substrate (21).

- 36. Method of producing a collimating system of at least one of claims 1 to 30, the method comprising the following steps:**
- a) Providing at least one glass substrate (11, 12),**
  - b) Positioning at least one polymer lens (1, 2, 3, 4) onto at least one side of the substrate.**
- 37. Method according to claim 36, wherein the step of positioning the polymer lens (1, 2, 3, 4) onto the substrate (11, 12) comprises the following steps:**
- b1) Dropping liquid polymer resin onto the substrate (11, 12) at pre-defined positions,**
  - b2) Curing the polymer resin.**
- 38. Method according to claim 37, wherein the polymer resin is cured with UV light.**
- 39. Use of a collimating system of at least one of claims 1 to 30 for 3D imaging and sensing, distance measurement, depth measurement, face recognition, object recognition, animation, 3D Modeling, 3D scanning, mobile payment, finger print sensor, Augment Reality/Virtual Reality and/or facial beautification.**