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(54) Title: PROCESS FOR PROVIDING FLUORESCENCE TO A DENTAL CERAMIC BODY

PL Intensity (arb. unit)

Wavelength (nm)

Legend (from top to bottom):

- 43 μg
- 215 μg
- 431 μg
- 862 μg
- 2'154 μg
- 3'016 μg
- 3'448 μg
- 8'970 μg
- 89'699 μg
- Undoped

Fig. 1

(57) Abstract: The present invention relates to a process for providing fluorescence to a dental ceramic body by treating at least a portion of the outer surface of the dental ceramic body or a precursor thereof with a bismuth containing substance. The invention is characterized by the steps of a) placing the dental ceramic body or the precursor thereof into a closeable container, in particular a crucible; b) generating a bismuth containing atmosphere in the container and c) exposing at least a portion of the outer surface of the dental ceramic body or of the precursor to the bismuth containing atmosphere at a temperature above 1000°C.

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Process for providing fluorescence to a dental ceramic body

The present invention relates to a process for providing fluorescence to a dental ceramic body according to the 5 preamble of claim 1.

The present invention further relates to a dental ceramic body according to the preamble of claim 11, in particular to a prosthetic element for use in a dental restoration.

The aesthetics of a dental restoration depends to an 10 important part on its translucency and color, which ideally closely resemble the one of a natural tooth.

From an aesthetical point of view, ceramics, such as zirconia and/or alumina ceramics, are particularly well suited as restorative materials, because of their ability 15 to provide excellent cosmetic results owed to their colour and their adequate reflection and transmission of light. In addition, these ceramics are biocompatible and exhibit good mechanical strength when subjected to masticatory efforts.

20 In order to adequately mimick the appearance of a natural tooth, also its inherent luminescence, in particular the fluorescence of the dentin tissue, needs to be taken into account.

25 Fluorescence refers to the phenomenon of light being emitted by a substance that has absorbed light or other electromagnetic radiation. Typically, the emitted light is of longer wavelength and, therefore, lower energy than the absorbed radiation.

In a natural tooth, the fluorescent properties are such that ultraviolet light is absorbed and visible light in the blue spectrum is emitted. Due to the high amount of light in the blue spectrum generated, a natural tooth 5 often appears whiter and brighter in daylight than restorative materials.

Efforts have, thus, been taken to adapt the fluorescence intensities of restorative materials as closely as possible to that of human teeth, in particular the enamel 10 and dentin tissue, to ensure an acceptable reproduction of these qualities in aesthetic restorations.

US 2012/0012789, for example, relates to a fluorescent zirconia material as a dental material comprising a fluorescent component and emitting fluorescence when 15 excited with a light of a predetermined wavelength. The fluorescent component includes a fluorescent material including at least one kind of $Y_2SiO_5:Ce$, $Y_2SiO_5:Tb$, $(Y, Gd, Eu)BO_3$, $Y_2O_3:Eu$, $YAG:Ce$, $ZnGa_2O_4:Zn$ and $BaMgAl_{10}O_{17}:Eu$. According to US 2012/0012789, the fluorescent material is 20 mixed in the form of fluorescent powder to the raw material powder.

FR 2 781 366 A1 relates to a dental ceramic composition essentially consisting of yttria-stabilized zirconia, a colouring filling material and impurities, the colouring 25 filling material consisting of Fe_2O_3 , Bi_2O_3 and CeO_2 . The content of Fe_2O_3 is according to FR 2 781 366 A1 preferably between 0.03 wt.-% and 0.1 wt.-%.

Further, WO 2014/164199 deals with the problem of mimicking the natural tooth appearance in dental 30 restorations taking into account the individual degrees of color and brightness of the hard dental tissues, e.g. of

enamel and dentin. In this regard, WO 2014/164199 suggests a solution for colouring and imparting fluorescence to a zirconia dental article, the solution comprising a solvent, a colouring agent comprising ions selected from 5 Tb, Er, Pr, Mn and combinations thereof, and a fluorescing agent comprising ions of Bi.

A solution for treating the surface of a pre-sintered dental ceramic is further disclosed in WO 2013/022612. Specifically, WO 2013/022612 aims at avoiding a complete 10 diffusion of the composition into the pores of the pre-sintered dental ceramic so that a defined application of the colouring solution can be accomplished. To this end, WO 2013/022612 suggests a non-water based solution comprising a solvent other than water, an effect agent 15 causing either colouring, providing fluorescence or a combination thereof, and a complexing agent.

Both the solutions suggested in WO 2013/022612 and in WO 2014/164199 are to be applied on a porous dental article, typically by means of a brush. According to WO 20 2014/164199, the preferred time of treatment is preferably 1 to 3 minutes.

Often, there is the case that the dental ceramic already has the desired colour, but needs to be provided with fluorescence only, i.e. without changing the colour. If 25 this is to be achieved by treating the dental ceramic with a solution according to e.g. WO 2013/022612, drying of the treated dental ceramic is typically required in order to avoid i.a. inhomogeneous colour effects. Inhomogeneities in the colouring can in particular arise from the method 30 of applying the solution, as it is for example the case when using a brush.

According to both WO 2013/022612 and WO 2014/164199, drying of the treated ceramic article typically takes about 1 to 3 hours. Overall, the treatment of the ceramic with the solution and the drying of the solution 5 results in a time-consuming process.

In order to streamline the process of providing fluorescence to a dental ceramic body, a time-saving but nevertheless simple process would be desirable.

The problem to be solved by the present invention is, 10 thus, to provide a process for providing fluorescence to a dental ceramic body in a simple and time-saving manner.

The problem is solved by the subject matter of claim 1. Preferred embodiments of the invention are defined in the claims dependent on claim 1.

15 According to claim 1, the present invention relates to a process for providing fluorescence to a dental ceramic body by treating at least a portion of the outer surface of the dental ceramic body or a precursor thereof with a bismuth containing medium.

20 The process is characterized by the steps of

- a) placing the dental ceramic body or the precursor thereof into a closeable container, in particular a crucible;
- b) generating a bismuth containing atmosphere in 25 the container and
- c) exposing at least a portion of the outer surface of the dental ceramic body or of the precursor to

the bismuth containing atmosphere at a temperature above 1000°C.

It has surprisingly been found that at a temperature above 1000°C, bismuth, in particular in the form of bismuth oxide, penetrates into the dental ceramic body in an amount sufficient for providing fluorescence closely resembling the one of a natural tooth. In this context, bismuth can also be referred to as a "dopant".

Specifically, the dopant bismuth diffuses into the ceramic material, whereby it moves through the crystal lattice of the ceramic material. This can take place in different ways, e.g. by empty space diffusion, whereby the dopant fills an empty place present in the crystal lattice. Alternatively or additional, the dopant can diffuse by inter lattice diffusion, whereby it moves in-between the atoms in the crystal lattice, or by changing of places, whereby the dopant is located in the crystal lattice and exchanged with a crystal lattice atom.

Unlike the processes suggested in the state of the art mentioned above, in particular in WO 2013/022612 and in WO 2014/164199, the process of the present invention allows providing fluorescence to the body without applying a solution comprising the fluorophor. The time-consuming steps of applying and drying the solution can thus be obviated.

Specifically and as will be discussed in further detail below, the present invention allows the process of providing fluorescence to be integrated in the sintering step and/or at least one of the post-sintering steps, e.g. the white firing, for preparing the dense ceramic body. Due to the fact that bismuth, specifically in the form of

bismuth oxide, is incorporated into the ceramic material simultaneously with at least one of the process steps that are normally performed for preparing the ceramic body, a very time-saving process can ultimately be achieved.

5 In addition, the present invention allows a homogeneous fluorescence to be provided, given the fact that the entire surface to be exposed is virtually facing the same atmosphere during step c). Inhomogeneities that might arise when e.g. a fluorophor containing solution is
10 applied by means of a brush, i.e. the typical application method according to WO 2013/022612, can thus be avoided.

Due to the fluorophor being bismuth, specifically in the form of bismuth oxide, a broad excitation spectrum as well as an emission spectrum resembling the one of a natural
15 tooth can be achieved. In particular, a broad excitation spectrum and a whitish-blue emission can be achieved.

Further, the present invention allows the desired fluorescence to be combined with a colouring of the dental ceramic body, which is typically performed before
20 providing fluorescence. In particular, the desired fluorescence can be applied on a coloured dental ceramic body by introducing bismuth, specifically in the form of bismuth oxide, in an amount at which there is no or no substantial discolouration.

25 As will be explained in more detail below, the fluorescence intensity can be easily tuned by adapting the amount of bismuth contained in the bismuth containing atmosphere.

30 Although the present invention allows bismuth, specifically in the form of bismuth oxide, to penetrate

into the ceramic material in an amount sufficient to provide the desired fluorescence, the amount can still be kept low enough not to have a negative impact on the mechanical stability of the dental ceramic body. In 5 particular, the tetragonal phase stability of zirconia is not influenced in a negative way by the doping with bismuth.

In addition, the biocompatibility of the dental ceramic body is not affected by the process of the present 10 invention.

The term "dental ceramic body" as used in the context of the present invention relates to any ceramic body suitable in the field of dentistry. The term can relate both to a pre-sintered ceramic body (often referred to as the 15 "porous ceramic body", to a sintered ceramic body (often referred to as the "dense ceramic body") or to a ceramic body after at least one post-sintering step, e.g. white firing. Accordingly, the term "precursor" can in particular relate to the green body obtained by pressing 20 the respective ceramic powder.

Preferably, the dental ceramic body comprises or essentially consists of zirconia and/or alumina. In particular zirconia shows outstanding properties with regard to aesthetic appearance and mechanical properties.

25 It is further preferred that the ceramic material of the body, in particular zirconia and/or alumina, is devoid of any metal that might quench the fluorescent properties provided by bismuth. Preferably, the ceramic material is devoid of iron (Fe).

30 According to a particular preferred embodiment, the dental

ceramic body comprises or essentially consists of yttria-stabilized zirconia. By using yttria-stabilized zirconia, a body having a particularly high mechanical strength can be achieved.

5 In this regard, the term "yttria-stabilized zirconia" encompasses - besides purely yttria-stabilized zirconia - any yttria-stabilized zirconia that is co-stabilized with a co-stabilizing agent, such as cerium, calcium, erbium and/or magnesium or their respective oxides.

10 Also, the term "yttria-stabilized zirconia" encompasses both a material based on zirconia particles co-precipitated with yttria as well as a material based on yttria-coated zirconia particles.

An example of an yttria-stabilized zirconia based on 15 zirconia particles co-precipitated with yttria is ZrO₂-TZP/TZP-A Bio-HIP® (ZrO₂) Bioceramic of Metoxit AG, Switzerland. The composition of this ceramic material comprises 92.1 to 93.5 weight-% ZrO₂, 4.5 to 5.5 weight-% Y₂O₃, 1.8 to 2.2 weight-% HfO₂ and 0.25 weight-% Al₂O₃. It 20 offers a particularly high mechanical stability and strength, in particular when prepared by hot isostatic pressing or by sintering with subsequent hot isostatic densification. A detailed description of the ceramic material is given in US-B-6,165,925, the disclosure of 25 which is incorporated herein in its entirety by reference.

Apart from yttria-stabilized zirconia, also e.g. ceria-stabilized or magnesia-stabilized zirconia as well as zirconia stabilized with strontium, ytterbium, gadolinium, calcium, erbium or neodymium or their oxides, 30 respectively, are thinkable and also encompassed by the term "dental ceramic" according to the present invention.

The dental ceramic body or the precursor thereof is according to step a) placed into a closeable container, particularly a crucible, more particularly a sintering crucible.

5 After step a), i.e. after placing the dental ceramic body or the precursor thereof into the container, a bismuth containing atmosphere is generated in the container in step b).

Typically, the bismuth containing atmosphere is generated
10 by the evaporation of a bismuth compound from a bismuth source containing the bismuth compound. In this regard, it is preferred that the bismuth source is placed in a region of the container other than the region where the dental ceramic body is placed. Bismuth, in particular in the form
15 of bismuth oxide, is according to this embodiment only incorporated into the ceramic material by way of exposure to the bismuth containing atmosphere; there is, however, no contact of the body with a bismuth containing substance other than the bismuth containing atmosphere. In
20 particular, there is no direct application of a bismuth containing solution on the dental ceramic body.

The fluorescence intensity to be provided can be adjusted by appropriately choosing the distance between the dental ceramic body and the bismuth source and/or the
25 concentration of bismuth in the bismuth containing atmosphere, which is again governed by the amount of the bismuth compound contained in the bismuth source. Further, it is possible to mask areas of the outer surface of the dental ceramic body at least partially, in order to
30 selectively provide non-fluorescent areas or areas of attenuated fluorescence intensity.

Thus, the process of the present invention allows for a relatively simple adjustment of the fluorescent properties of the dental ceramic body to the actual needs.

Alternatively to the bismuth compound being evaporated in 5 the container, it is also thinkable to produce a bismuth containing gas outside of the container, said gas being then introduced into the container to generate the bismuth containing atmosphere therein.

As mentioned, the container, into which the dental ceramic 10 body or its precursor is placed and in which a bismuth containing atmosphere is generated, is preferably a crucible. Alternatively, it can also be a furnace.

By the use of a crucible as closeable container, a 15 stagnant bismuth containing atmosphere can be obtained even if a relatively moderate amount of bismuth compound in the bismuth source is provided, said atmosphere containing bismuth in a concentration sufficient to allow for bismuth, in particular in the form of bismuth oxide, penetrating into the ceramic body to provide it with the 20 desired fluorescent properties. If exposure to the bismuth containing atmosphere is to be carried out in a conventional furnace, higher amounts of bismuth are necessary to achieve the desired effect, due to the large volume of the furnace and the aeration typically present 25 in the furnace.

The bismuth source containing the bismuth compound to be evaporated can be a liquid bismuth source, in particular containing or essentially consisting of molten bismuth oxide, a solution of bismuth nitrate, specifically bismuth 30 nitrate pentahydrate, and/or a solution of bismuth acetate. In this regard, the liquid bismuth source can in

some cases be dried and, hence, become solid before generating the bismuth containing atmosphere. Alternatively, a bismuth source can be used, which *ab initio* is solid, in particular bismuth-infiltrated 5 zirconia and/or alumina.

According to a preferred embodiment, the crucible confines an inner space having a volume in the range from 50 to 200 cm³, typically of about 100 cm³.

The container, and specifically the crucible, can for 10 example be made of alumina, platinum or a platinum alloy, specifically platinum-rhodium. In particular in view of embodiments, in which the bismuth source contains a relatively high amount of a bismuth compound, the container is preferably made of platinum or a platinum 15 alloy.

Given the high heat-resistance of platinum or a platinum alloy, specifically of platinum-rhodium, a temperature of higher than 1400°C can be chosen in step c) without negative consequences for the crucible, thereby allowing 20 all of the bismuth compound entering the gas phase, even in the case where a high amount of bismuth compound is provided. Consequently, a container of relatively large volume can be chosen, thereby also allowing to treat multiple dental ceramic bodies in one and the same 25 crucible simultaneously.

In particular in view of treating multiple dental ceramic bodies simultaneously, the bismuth containing source is preferably placed in a central area of the crucible, which upon heating gives rise to a uniform environment for 30 bodies that are equidistantly disposed around the bismuth source.

If necessary or appropriate, the bismuth source can be placed in a respective vessel, such as an alumina vessel, arranged in the crucible.

Typically, the bismuth containing atmosphere contains 5 bismuth in the form of bismuth oxide. This is in particular the case when an oxidizing atmosphere, e.g. air, is present, in which bismuth oxide is generated also in the case when the bismuth source contains e.g. bismuth nitrate pentahydrate.

10 Accordingly, it is further preferred that at least steps b) and c) are performed in the presence of oxygen, and most preferably in the presence of air. In this particular case, the bismuth containing atmosphere relates to air additionally containing bismuth oxide.

15 According to a particularly preferred embodiment, the atomic mass of bismuth in the bismuth source placed in the container is the range of 0.5 to 1000 mg per liter of volume of the container's inner space.

Accordingly, it is further preferred that the molar 20 concentration of bismuth in the bismuth containing atmosphere is in the range from about $1 \cdot 10^{-6}$ to about $1 \cdot 10^{-2}$ mol/liter, more preferably from about $2 \cdot 10^{-6}$ to about $5 \cdot 10^{-3}$ mol/liter. In this context, the concentration of bismuth relates to any form of bismuth present in the atmosphere, 25 and in particular encompasses bismuth oxide.

It has further been found that the exposure to the bismuth containing atmosphere under step c) of the process of the present invention is preferably performed at a temperature above 1200°C, preferably at a temperature above 1300°C. A 30 temperature at about 1450°C, corresponding to a typical

sintering temperature for yttria-stabilized zirconia ceramic, is particularly preferred due to the fact that at this temperature bismuth, in particular in the form of bismuth oxide, efficiently diffuses into the body. At this 5 particularly preferred temperature, there is thus no discolouration which might arise when a relatively high amount of bismuth is deposited on the ceramic without diffusing into the body and therefore accumulating on the outer surface of the body, rather than being incorporated 10 in the body.

As mentioned above, fluorescence is according to the present invention provided by bismuth, specifically in the form of bismuth oxide, penetrating into the dental ceramic body and thereby becoming incorporated into the ceramic 15 material.

The depth of penetration of bismuth, in particular in the form of bismuth oxide, is preferably 500µm at most, more preferably 400µm at most, most preferably 300µm at most. According to a specific embodiment, the depth of 20 penetration is in the range from 200µm to 250µm.

As also mentioned above, the providing of fluorescence is preferably integrated in the sintering step and/or at least one of the post-sintering steps normally performed when preparing the dental ceramic body. According to a 25 particularly preferred embodiment, steps b) and c) are performed during sintering the dental ceramic body and/or during a post-sintering step, since this allows a fluorescent ceramic body to be obtained in a most time-saving manner. In this regard, the performing of steps b) 30 and c) during the sintering step is of particular relevance, since at the sintering temperature a highly

efficient penetration of bismuth, specifically in the form of bismuth oxide, is achieved.

According to a specifically preferred embodiment, the present invention thus relates to a process comprising the 5 steps of providing fluorescence to a dental ceramic body by treating at least a portion of the outer surface of the dental ceramic body or a precursor thereof with a bismuth containing substance, characterized by the steps of

- 10 α) placing a precursor of the dental ceramic body thereof into a sintering crucible;
- β) generating a bismuth containing atmosphere in the sintering crucible and
- 15 γ) sintering the precursor to the dental ceramic body whereby at least a portion of the outer surface of the precursor is exposed to the bismuth containing atmosphere.

Alternatively, it can also be preferred to perform steps b) and c) during a post-sintering step, and more particularly during the final post-sintering step. This is 20 in particular the case when the lower temperature present during the post-sintering steps is sufficient for an efficient incorporation of bismuth and if loss of bismuth already incorporated into the ceramic material, which potentially can occur during heat treatment, shall be 25 diminished.

Since fluorescence is according to the described process obtained by bismuth, in particular in the form of bismuth oxide, penetrating into the dental ceramic body and since the fluorophor is therefore only present in a surface-near

region reaching down from the surface to the depth of penetration, the body is particularly well suited for applications for which no or only unsubstantial further machining is required in order obtain the final dental 5 article. This can e.g. be the case if the final dental article is a prosthetic element, the shape of which corresponds essentially to the form of the densily sintered dental ceramic body.

For these applications, pre-sintered blocks are typically 10 pre-shaped with the aid of CAD/CAM systems into the shape of the prosthetic element, but having a size 25 to 30 % higher than the final element to compensate for the sintering shrinkage. The final sintering temperature is between 1350°C and 1550°. Apart from bismuth or the 15 bismuth containing compound penetrating into the body, this processing reduces the level of tension present and prevents the transformation from the tetragonal phase to the monoclinic phase, which leads to a final surface virtually free of the monoclinic phase.

20 According to a further preferred embodiment of the process, the dental ceramic body to which fluorescence is to be provided is, therefore, a dental article, preferably an implant or a prosthetic element for use in a dental restoration, more preferably a crown, a bridge, an 25 abutment, an onlay and/or an inlay.

The relevance of the dental ceramic body for use as a dental implant can be explained by the fact that any loss of natural bone structure, e.g. as a result of bone resorption, can result in soft-tissue shrinkage due to the 30 lack of boney support, which ultimately can lead to the situation that a portion of the implant becomes visible.

Since the dental implant according to the present invention can both in colour and luminescence be closely adapted to the colour and luminescence of a natural tooth, an unesthetic situation can be circumvented also under 5 these circumstances.

In addition to the process described above, the present invention further relates to a dental ceramic body obtainable by the process.

In this regard, the present invention specifically relates 10 to a dental ceramic body based on zirconia and/or alumina comprising or essentially consisting of

a core region being at least essentially free of bismuth and

15 a surface region surrounding the core region and containing bismuth,

characterized in that the surface region in which bismuth is contained reaches down from the surface to a depth of 500 μm at most.

Given the fact that bismuth is only contained in a surface 20 region, but is in essence absent from the remainder of the body, any impact of the change in the material on the body's mechanical properties can be kept to a minimum.

In restricting the presence of bismuth to the surface region, i.e. down to a depth of 500 μm at most, the 25 present invention is in clear contrast to technologies, which aim at a relatively deep penetration of the fluorescing agent. In particular, the present invention is in contrast to the technology taught in WO 2014/164199, according to which an open pore structure is required for

sufficiently absorbing the solution comprising the colouring and the fluorescing agent and thus to achieve a penetration depth of 5 mm.

In contrast to the penetration depth aimed at in WO 5 2014/164199, a much lower penetration depth of 500 µm at most is achieved according to the process of the present invention, due to the bismuth diffusing from the gas phase into the body, rather than by being contained in a solution that is absorbed by the body.

10 If step c) of the process of the present invention is carried out during sintering, a penetration depth of 500 µm at most can be achieved when applying common sintering temperatures, and in particular a temperature of about 1450°C, given that the densification of the material 15 during sintering takes place relatively rapidly. Thus, the skilled person, who has become aware of the inventive process and its preferred embodiments, readily knows how to prepare the dental ceramic body.

20 As a result of the lower penetration depth, the dental ceramic body of the present invention allows to eliminate fluorescent properties in selected areas of the body in a very simple manner. Specifically, this can be achieved by removing material from the surface region or a portion thereof in the respective areas of the body.

25 Since by the process of the present invention bismuth diffuses into the material of the body, a concentration gradient within the surface region is typically obtained. Specifically, the concentration of bismuth decreases in direction from the surface of the body towards its core 30 region in a gradual manner. Due to this concentration gradient, the present invention further allows attenuating

the fluorescence intensity of the body by partially removing the material from the surface region. In other words, material can be abraded down to a depth, at which the amount of bismuth is low enough for providing the 5 desired attenuated fluorescence intensity.

In contrast to the body obtained according to WO 2014/164199, the dental ceramic body of the present invention allows for a post-processing in order to further adjust the fluorescent properties of the body.

10 Preferably, the molar amount of bismuth contained in the surface region is less than 0.5 mol-%, preferably less than 0.4 mol-%, more preferably less than 0.3 mol-%, and most preferably less than 0.2 mol-%. Although sufficient for providing the desired fluorescent properties to be 15 dental ceramic body, these amounts are still low enough to further decrease any potential impact on the mechanical properties of the material.

It is further preferred that the amount of bismuth contained in the surface region is higher than 0.06 mol-%, 20 preferably higher than 0.08 mol-%, more preferably higher than 0.1 mol-%, in order to provide sufficient fluorescence to the body.

As mentioned, the dental ceramic body is particularly well suited for applications for which no or only unsubstantial 25 further machining is required in order obtain the final dental article. In particular, the dental ceramic body is a prosthetic element for use in a dental restoration, preferably a crown, a bridge, an implant, an abutment, an onlay and/or an inlay.

Alternatively to the embodiment, in which step c) is carried out during sintering, the process of the present invention also encompasses the embodiment, in which the dental ceramic body or a precursor of the dental ceramic 5 body is exposed to the bismuth containing atmosphere in step c), said dental ceramic body or precursor being non-densified and/or porous. In terms of a sintering process, a green body or a brown body of the dental ceramic body can be subjected to the exposure according to step c). The 10 term "brown body" thereby relates to the green body after burning off the binder.

In other words, step c) can be performed prior to the actual sintering step. Given the lower density of the material in comparison to the densified material obtained 15 during sintering, bismuth can diffuse deeper into the porous ceramic body or precursor. When choosing a sufficiently long time of exposure, this can lead to the point at which bismuth is distributed throughout the whole porous ceramic body or precursor, which can then be 20 subjected to the final sintering at a higher temperature to obtain the dense ceramic body.

For this alternative embodiment, the temperature of step c) is preferably above the evaporating temperature of the bismuth compound, but below the final sintering 25 temperature of the ceramic, and specifically is in a range from 1100°C to 1200°C.

The present invention, thus, also relates to a dental ceramic block obtainable by the process specified above, the bismuth contained being distributed throughout the 30 whole block. This dental ceramic block can either be non-

densified, i.e. in the pre-sintered state, or densified, i.e. in the sintered state.

Specifically, the present invention relates to a dental ceramic block containing bismuth distributed throughout 5 the whole block, the amount of bismuth being higher than 0.06 mol-%, preferably higher than 0.08 mol-%, more preferably higher than 0.1 mol-%.

The features, which in the context of the process and the dental ceramic body of the present invention have been 10 presented as preferred, are likewise preferred features of the dental ceramic block and of the process for preparing the dental ceramic block, respectively. In particular, the dental ceramic block is likewise based on zirconia and/or alumina, as discussed in the context of the process.

15

Whereas for some applications the dental ceramic body is particularly well suited for applications for which no or only unsubstantial further machining is required in order 20 obtain the final dental article, there are some applications, in which the final dental article is obtained by milling a block of the dense ceramic material. This can e.g. be the case for a dental implant. Apart 25 final dental articles, such as prosthetic elements for use in a dental restoration, dental implants, individualized abutments or complete dentures, the term "dental ceramic body" also encompasses dental ceramic blocks, in particular semi-finished blocks or blanks, in particular blanks with pre-fabricated connections and block for further chair-side modifications.

For applications, in which the final dental article is obtained by milling a block of the dense ceramic material, the methods according to WO 2013/022612 and WO 2014/164199 are unsuitable, since by the milling the surface near 5 region containing the fluorescent compound is lost.

In particular with regard to a dental ceramic body which after sintering is to be milled into the final dental article, more particularly a dental implant, it would thus be desirable to provide a process for providing a 10 fluorescent dental ceramic material which even after milling maintains its fluorescent properties.

According to a second aspect, the problem to be solved by the present invention is to provide a process for providing a fluorescent dental ceramic body which after 15 milling body into the final dental article maintains its fluorescent properties.

The problem of this second aspect is solved by the process according to claim 13.

The present invention thus also relates to a process for 20 providing a fluorescent, dense ceramic body based on zirconia and/or alumina comprising the steps of

- A) providing a ceramic precursor powder containing apart from zirconia and/or alumina, respectively, bismuth oxide in an amount of 25 lower than 0,7 mol-%,
- B) pressing the ceramic precursor powder to form a green body,
- C) debinding the green body obtained in B) to form a porous brown body, and

D) sintering the porous brown body obtained in C) to obtain the fluorescent, dense ceramic body.

As mentioned above, the ceramic is preferably zirconia, more preferably yttria-stabilized zirconia.

5 In this regard, the ceramic precursor powder can specifically be a zirconia powder to which bismuth-doped yttria powder is admixed. In this specific case, bismuth diffuses out of the bismuth-doped yttria during sintering, which results in the doping of the yttria-stabilized
10 zirconia.

Alternatively, the ceramic precursor powder can be prepared by admixing a bismuth containing solution to the yttria-stabilized zirconia powder, which likewise results in the doping of the yttria-stabilized zirconia.

15 According to the invention, bismuth oxide is contained in the ceramic precursor powder in an amount of lower than 0.7 mol-%. In this regard, it is particularly preferred that the amount of bismuth oxide is high enough to provide the desired fluorescent properties, but low enough not to
20 interfere substantially with the colour of the ceramic body to be provided.

In particular in view of providing sufficient fluorescence to be seen by the human eye, the amount of bismuth oxide contained in the ceramic precursor powder is preferably
25 higher than 0.06 mol-%, more preferably higher than 0.08 mol-%, most preferably higher than 0.1 mol-%. Thus, the amount of bismuth or bismuth oxide being used as a fluorophor is higher than if it was used for the sole purpose of providing a defined colour to the material, as
30 it is taught in FR 2 781 366 A1, according to which the

amount of bismuth oxide is in any case to be kept below 0.2 wt.-%, i.e. well below 0.06 mol-%, since this is an essential feature of its teaching.

The ceramic precursor powder according to A) can, thus, in 5 particular be referred to as bismuth-doped zirconia, more particularly bismuth-doped yttria-stabilized zirconia.

Bismuth-doped yttria-stabilized zirconia exhibits a particularly high emission intensity, which - without wanting to be bound by the theory - can be explained by 10 the fact that in the final dense ceramic body the main crystalline phase is doped, i.e. the stabilized zirconia, rather than the yttria, which is contained in much lower concentration. Also with regard to the bismuth-doped 15 yttria-stabilized zirconia obtainable by the process according to the second aspect, the tetragonal phase stability of zirconia is not influenced in a negative way by the doping with bismuth.

Specifically, bismuth oxide is not used in a colouring filling material for the purpose of providing a defined 20 colour to the ceramic body. According to this specific embodiment, bismuth-doping serves the sole purpose for providing fluorescence to the ceramic body. In analogy to the above and in further distinction to the teaching of FR 2 781 366 A1, the ceramic precursor powder is preferably 25 devoid of iron (Fe), in order to prevent quenching of the fluorescent properties provided by bismuth.

In the dental ceramic body obtained by this process, the fluorophor bismuth is homogeneously distributed throughout the volume of the body. After milling, i.e. after 30 subtraction of the surface region in at least a portion of the body, the fluorescent properties are fully maintained.

This is of particular relevance for preparing a dental implant or a dental implant abutment made of a fluorescent ceramic material, as the implant or abutment is typically obtained by milling it from a dental ceramic block.

5 Accordingly, it is preferred that the process further comprises step

E) milling the dental ceramic body to a dental article, in particular to a dental implant or a dental implant abutment.

10 As the case may be, step C) can further comprise the sub-step of pre-sintering the green body after debinding. Thus, an intermediate body with good machinability is achieved, which can in particular be preferred in view of the preparation of a dental implant or a dental implant
15 abutment.

20 Preferably, the sintering of D) is carried out in the presence of a bismuth containing atmosphere. Thus, the bismuth oxide vapour pressure can be maintained sufficiently high in order to diminish or prevent diffusion of bismuth out of the ceramic material.

With regard to the composition and to the generation of the bismuth containing atmosphere, the features which have been described as preferred for the process according to the first aspect likewise are preferred for the process
25 according to the second aspect.

Also with regard to the material of the dental ceramic body, the features described as preferred for the process of the first aspect are likewise preferred for the process of the second aspect.

As mentioned, the amount of bismuth contained in the dental ceramic body achieved by the process of the first aspect or by the process of the second aspect is in particular higher than 0.06 mol-%, preferably higher than 5 0.08 mol-%, more preferably higher than 0.1 mol-%. Further, the amount of bismuth contained in the dental ceramic block is in particular lower than 0.7 mol-%, preferably lower than 0.5 mol-%, more preferably lower than 0.3 mol-%.

10 The present invention thus also relates to a dental ceramic body, specifically to a dental ceramic block as well as to a final dental article, containing bismuth in an amount of higher than 0.06 mol-%, preferably higher than 0.08 mol-%, more preferably higher than 0.1 mol-%, 15 based on the total composition.

The present invention is exemplified and illustrated by way of the following examples in combination with attached

Fig. 1 showing the emission spectra (for an excitation wavelength of 365 nm) of various samples 20 prepared according to the process of the present invention invention; and

Fig. 2 showing the excitation spectrum (for an emission wavelength of 460 nm) of a sample prepared according to the process of the present 25 invention invention.

EXAMPLES

Example 1 (relating to the first aspect of the present invention)

1.1 g of partially stabilized zirconia powder containing
5 3.0 mol% yttria (Tosoh TZ-3YSB-E) was pressed with 65 kN
(resulting in a pressure of 171 MPa) to a disc-shaped
green body having a diameter of 22 mm.

The resulting green body was then subjected to a heat
treatment for debinding (at about 300° to 350°C) and
10 burning the carbon residues (at about 700°C), followed by
pre-sintering at 1050°C.

The pre-sintered body was then placed in a crucible
together with predefined amounts of a bismuth compound,
namely of 1% bismuth nitrate in nitric acid (obtained by
15 adding 100 mg of bismuth nitrate pentahydrate to 10 ml of
1% nitric acid) or of bismuth (III) oxide.

Specifically, an alumina vessel having the shape of a
hollow cylinder with an outer diameter of 20.5 mm and a
height of 18 mm was put into a crucible with inner
20 dimensions of 42 x 92 x 25.8 mm. The vessel was placed in
a region of the crucible other than the region where the
pre-sintered body was placed.

For each of the samples, different amounts of bismuth
nitrate or bismuth (III) oxide were given into the alumina
vessel and, in case of the bismuth nitrate being in
solution, were dried in a drying chamber. The respective
25 amounts are given in Table 1:

Table 1

Sample No.	Bismuth compound	Mass of bismuth compound	Volume of solution (µl)	Atomic mass of Bi (µg)
1	Bismuth nitrate	0.1	10	43.08
2	Bismuth nitrate	0.5	50	215.41
3	Bismuth nitrate	1.0	100	430.82
4	Bismuth nitrate	2		861.65
5	Bismuth nitrate	5		2154.12
6	Bismuth nitrate	7		3015.76
7	Bismuth nitrate	8		3446.59
8	Bismuth oxide	10		8969.90
9	Bismuth oxide	100		89699.3

Sintering of the pre-sintered body was then performed in the presence of a bismuth containing atmosphere generated

from evaporation of the bismuth compound. Specifically, dwelling was performed at a sinter temperature of 1450 °C for 2 hours.

As shown in Fig. 2, sample 3 prepared according to the 5 process of the present invention produced an excitation maximum at 315 nm. As further shown in Fig. 1, the emission maximum produced was at 455 or 460 nm, whereby the highest fluorescence intensity was achieved for the sample using 8.97 mg atomic mass of bismuth (sample 8).

10 Thus, both the use of bismuth nitrate as well as of bismuth oxide led to the generation of a bismuth-containing atmosphere during the sintering process and consequently to the incorporation of bismuth, specifically in the form of bismuth oxide, in an amount sufficient to 15 impart fluorescent properties closely resembling the one of a natural tooth. Specifically, a bismuth oxide containing atmosphere was generated due to the evaporation of bismuth oxide in one case and to due to the evaporation and oxidation of bismuth nitrate in the other case.

20 Further experiments have shown that using a zirconia sample infiltrated with a bismuth nitrate solution of higher concentration (100 mg/ml) as bismuth source likewise led to the generation of a bismuth containing atmosphere during sintering.

25 The visual inspection of the samples under UV-light showed that the upper side of the sample, i.e. the side that was directly exposed to the bismuth-containing atmosphere, was homogeneously doped with bismuth. Thus, a uniform incorporation of bismuth was achieved on this side.

The results shown in Fig. 1 further suggest that the fluorescence intensity is tunable by the amount of bismuth compound put into the crucible and, hence, the concentration of bismuth compound in the bismuth containing atmosphere.

A fluorescence intensity under 365 nm similar to the one of a natural tooth was obtained for an atomic bismuth mass of 3.45 mg in the crucible. Given the volume of about 100 ml of the crucible's inner space, the optimum mass concentration of bismuth was therefore about 0.035 g/l.

Example 2 (relating to the second aspect of the present invention)

Preparation of bismuth-doped yttria

A powder of bismuth doped yttria ($\text{Y}_2\text{O}_3:\text{Bi}$) was prepared by dissolving 19.96 g of yttrium (III) nitrate hexahydrate ($\text{Y}(\text{NO}_3)_3 \cdot 6 \text{ H}_2\text{O}$) and urea ($\text{CH}_4\text{N}_2\text{O}$) in nitric acid (10%) and adding 2.15 ml of a solution of bismuth (III) nitrate·pentahydrate ($\text{Bi}(\text{NO}_3)_3 \cdot 5 \text{ H}_2\text{O}$) in nitric acid (10mg/1ml).

The mixture was then dried at 95°C in a rotational evaporator at 200 mbar vacuum.

The powder was then fired at 1000°C for 1 hour in air in an alumina crucible.

The cake received from firing were broken up and crushed to a coarse powder. This powder was washed with deionized water to remove remaining flux and dried in a rotational evaporator. The powder was then sieved with 250 µm mesh.

Preparation of ceramic precursor powder

Zirconia powder TZ-3YSB-E was blended with $\text{Y}_2\text{O}_3:\text{Bi}$. Specifically, two mixtures of 10 g were prepared with either 1 wt.-% or 5 wt.-% of $\text{Y}_2\text{O}_3:\text{Bi}$ powder according to 5 Table 2.

Table 2

Sample No.	Percentage $\text{Y}_2\text{O}_3:\text{Bi}$ powder (wt-%)	Mass of $\text{Y}_2\text{O}_3:\text{Bi}$ powder (g)	Mass of zirconia powder (g)
10	1.0	0.1	9.9
11	5.0	0.5	9.5

The mixtures were given in mixer beakers and mixed in the 10 speedmixer for 1 minute at 800 rpm.

Samples were then pressed and sintered as described for Example 1 above.

Fluorescence measurements revealed for an excitation wavelength of 365 nm an emission maximum at about 415 nm. 15 The excitation maximum lies at about 328 nm with another maximum at 304 nm.

Claims

1. Process for providing fluorescence to a dental ceramic body by treating at least a portion of the outer surface of the dental ceramic body or a precursor thereof with a bismuth containing substance, characterized by the steps of
 - a) placing the dental ceramic body or the precursor thereof into a closeable container;
 - b) generating a bismuth containing atmosphere in the container and
 - c) exposing at least a portion of the outer surface of the dental ceramic body or of the precursor to the bismuth containing atmosphere at a temperature above 1000°C.
- 15 2. Process according to claim 1, characterized in that the dental ceramic body comprises or essentially consists of zirconia and/or alumina, in particular yttria-stabilized zirconia.
- 20 3. Process according to claim 1 or 2, characterized in that the bismuth containing atmosphere is generated by the evaporation of a bismuth compound from a bismuth source containing the bismuth compound, the bismuth source being placed in a region of the container other than the region where the dental ceramic body is placed.

4. Process according to any of the preceding claims, characterized in that the closeable container is a crucible.
5. Process according to any of the preceding claims, characterized in that the bismuth containing atmosphere contains bismuth in the form of bismuth oxide.
6. Process according to any of the preceding claims, characterized in that the molar concentration of bismuth in the bismuth containing atmosphere is in the range from $1 \cdot 10^{-6}$ to $1 \cdot 10^{-2}$ mol/liter, preferably from $2 \cdot 10^{-6}$ to $5 \cdot 10^{-3}$ mol/liter.
7. Process according to any of the preceding claims, characterized in that exposing the dental ceramic body or the precursor to the bismuth containing atmosphere according to step c) is carried out at a temperature above 1200°C, preferably at a temperature above 1300°C and most preferably at a temperature of about 1450°C.
8. Process according to any of the preceding claims, characterized in that bismuth, in particular in the form of bismuth oxide, penetrates into the dental ceramic body, the depth of penetration being 500µm at most, preferably 400µm at most, more preferably 300µm at most, and most preferably is in the range from 200µm to 250µm.
9. Process according to any of the preceding claims characterized in that steps b) and c) are performed during sintering the dental ceramic body and/or during a post-sintering step.

10. Process according to any of the preceding claims, characterized in that the dental ceramic body is a dental article, preferably a prosthetic element for use in a dental restoration, more preferably a crown, 5 a bridge, an implant, an abutment, an onlay and/or an inlay.
11. Dental ceramic body based on zirconia and/or alumina comprising or essentially consisting of 10 a core region being at least essentially free of bismuth and a surface region surrounding the core region and containing bismuth, characterized in that the surface region in which bismuth is contained reaches down from the surface to 15 a depth of 500 μ m at most.
12. Dental ceramic body according to claim 11, wherein the molar amount of bismuth contained in the surface region is less than 0.5 mol-%, preferably less than 0.4 mol-%, more preferably less than 0.3 mol-%, and 20 most preferably less than 0.2 mol-%.
13. Process for providing a fluorescent dental ceramic body based on zirconia and/or alumina comprising the steps of 25 A) providing a ceramic precursor powder containing apart from zirconia and/or alumina, respectively, bismuth oxide in an amount of lower than 0,7 mol-%,

- B) pressing the ceramic precursor powder to form a green body,
- C) debinding the green body obtained in B) to form a porous brown body, and
- 5 D) sintering the porous brown body obtained in C) to obtain the fluorescent, dense ceramic body.

14. Process according to claim 13, wherein the sintering of D) is carried out in the presence of a bismuth containing atmosphere.

10 15. Process according to claim 13 or 14, further comprising step

- E) milling the dental ceramic body to a dental article, in particular to a dental implant or a dental implant abutment.

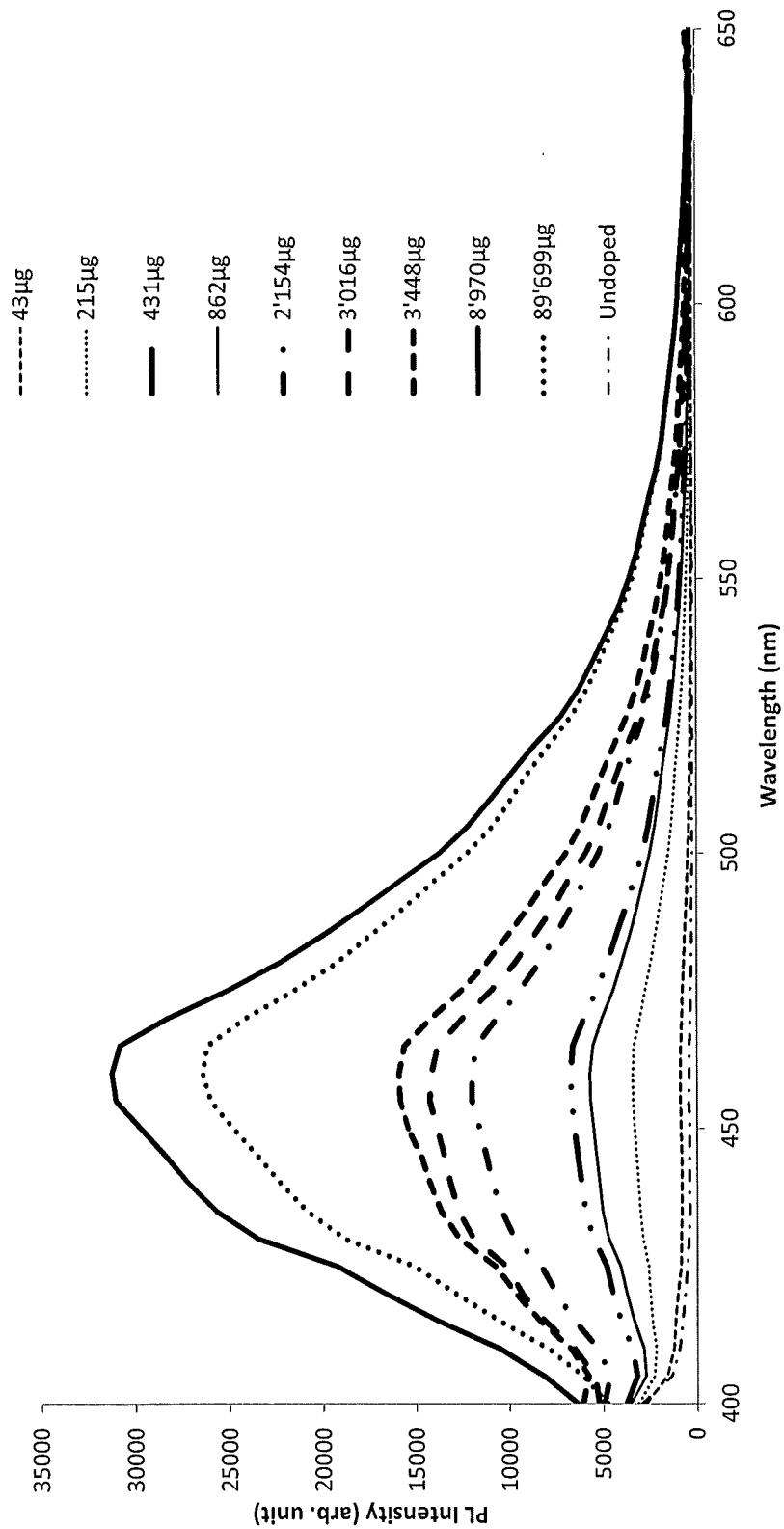


Fig. 1

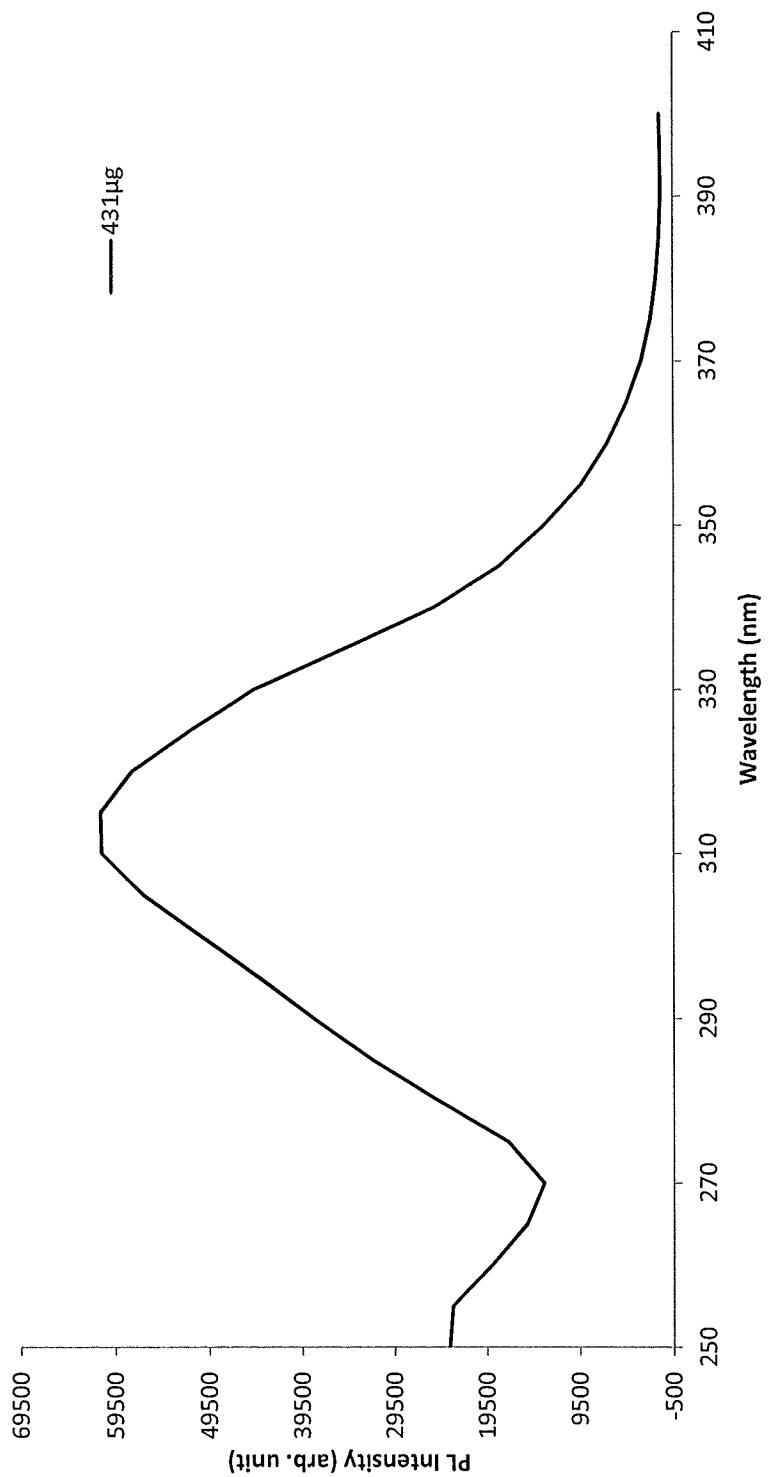


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/052543

A. CLASSIFICATION OF SUBJECT MATTER
INV. C04B41/87 C04B35/486 A61K6/02
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)
C04B A61K

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, WPI Data, COMPENDEX, BIOSIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 781 366 A1 (NORTON DESMARQUEST FINE CERAMI [FR]) 28 January 2000 (2000-01-28)	13-15
A	claims examples	1-12
A	----- WO 2014/164199 A1 (3M INNOVATIVE PROPERTIES CO [US]) 9 October 2014 (2014-10-09) cited in the application claims page 23, line 27 - line 28	1-15
X, P	----- WO 2015/084931 A1 (3M INNOVATIVE PROPERTIES CO [US]) 11 June 2015 (2015-06-11) page 1, line 6 - line 8	13,15
A, P	example 2 claims 11,12	1-12,14



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
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"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
13 April 2016	21/04/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Rosenberger, Jürgen

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/052543

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
FR 2781366	A1	28-01-2000	NONE	
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