(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
04 April 2019 (04.04.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/063241 A1

(51) International Patent Classification:
H01L 27/146 (2006.01)

(21) International Application Number:
PCT/EP2018/073541

(22) International Filing Date:
31 August 2018 (31.08.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
17306274.6 26 September 2017 (26.09.2017) EP

(71) Applicant: **THOMSON LICENSING** [FR/FR]; 1-5, rue Jeanne d'Arc, 92130 Issy-les-Moulineaux (FR).

(72) Inventors: **BORISKIN, Artem**; c/o Technicolor 975 avenue des Champs Blancs, 35576 CESSON-SEVIGENE (FR). **DAMGHANIAN, Mitra**; c/o Technicolor 975 avenue des Champs Blancs, 35576 CESSON-SEVIGENE (FR). **SHRAMKOVA, Oksana**; c/o Technicolor 975 avenue des Champs Blancs, 35576 CESSON-SEVIGENE (FR). **DRAZIC, Valter**; c/o Technicolor 975 avenue des Champs Blancs, 35576 CESSON-SEVIGENE (FR). **BLONDE, Laurent**; c/o Technicolor 975 avenue des Champs Blancs, 35576 CESSON-SEVIGENE (FR).

(74) Agent: **WINDAL, Gaëlle**; Vidon Brevets et Stratégies, 16B rue de Jouanet, BP 90333, 35703 RENNES Cedex 7 (FR).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) Title: IMAGE SENSOR COMPRISING PIXELS FOR PREVENTING OR REDUCING THE CROSSTALK EFFECT

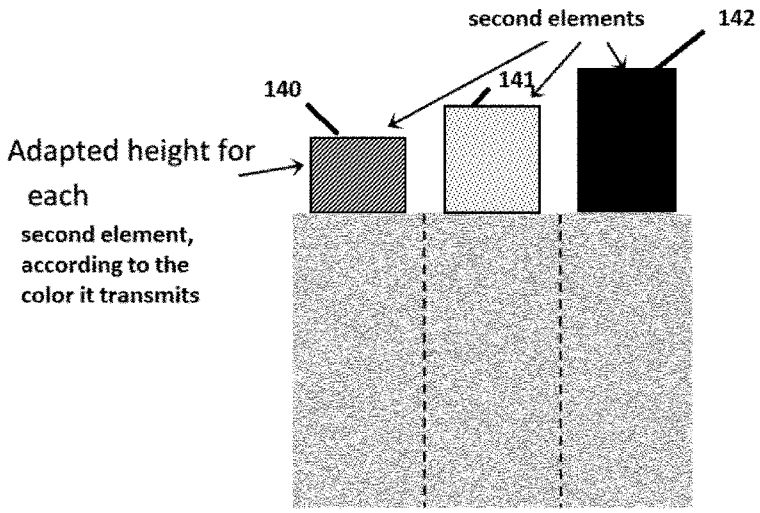


FIG.14

(57) Abstract: The present disclosure concerns an image sensor comprising a set of pixels, wherein each pixel of the set comprises a first and a second element, the first element comprising a photodiode module unit, and the second element being an element for filtering color and focusing incident light into said first element. The image sensor further comprises at least two consecutive pixels from the set of pixels, for which first elements are put side by side, and wherein the image sensor comprises a gap between second elements of said at least two consecutive pixels.

WO 2019/063241 A1

[Continued on next page]

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

Image sensor comprising pixels for preventing or reducing the crosstalk effect

Technical Field

The present disclosure pertains to the technical field of image sensors for acquiring image data. More precisely, it relates to the design of a specific pixel architecture, and a way to combine several of these pixels within an image sensor.

Background

This section is intended to introduce the reader to various aspects of art, which may be related to various aspects of the present invention that are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, these statements are to be read in this light, and not as admissions of prior art.

The design of a pixel architecture, and more generally the design of an image sensor is a process in which one skilled in the art should overcome several technical problems.

Indeed, usually, one skilled in art should cope with the crosstalk effect, the pixel size shrinkage limit, the shadowing effect, as well some constraints related to the manufacturing.

More precisely, crosstalk undermines the optical efficiency of an image sensor but it can be considered as a separate problem as minimizing cross talk can be investigated independent from the optical efficiency of the image sensor. Crosstalk is a common issue in the image sensors especially those with small pixels. The higher the thickness of the optical stack, the bigger is the risk for crosstalk. In addition, it should be noted that the crosstalk is by design related to the thickness of the optical stack layer. Moreover, the crosstalk increases especially when there is not a perfect optical insulation between the pixels. The crosstalk issue is more evident at low f-numbers of the main lens.

Concerning the pixel size shrinkage limit, it should be noted that the trend for smaller pixel sizes in the image sensor is slowed down since wavelength and absorption length are constant despite the pixel shrinkage. When the wavelength is comparable with the aperture

size of one pixel, diffraction brings on crosstalk, which is a major issue, introducing errors and undermining the light collection efficiency of the pixels. Therefore, techniques for enabling realize such shrinkage capability are required.

Concerning the shadowing effect, it is induced by the micro lenses of the pixels. Indeed, the curved surface of the microlenses, which is the common design in the on-chip optics of the image sensors, has a shadowing effect on neighboring pixels. The shadowing can limit the maximum angle of the incident light as bigger angles will be blocked by the neighboring pixels and therefore light never reaches the intended pixel. The case is more noticeable for wide angle captures, smaller f-numbers and when the radius of curvature of the microlenses on the image sensor are small. Moreover, the shadowing effect can increase crosstalk and reduce optical efficiency.

At last, concerning the fabrication complexity, it should be noted that the realization of the color filters (usually three colors and sometimes white or transparent pixels in addition) in current image sensors requires several coating, lithography and etching steps. This process is expensive and requires very precise alignment techniques. On top of that, the microlens array should be realized with another coating, lithography and thermal treatment sequence. This complex fabrication process can challenge the yield, especially in an array structure like an image sensor, where a few defects can fail the whole device. In general, simpler fabrication processes are desirable as it improves the yield. For example, researchers try to find out simpler processes that can be in the form of a process with less fabrication steps, or a process which replaces critical (error prone, low yield) fabrication steps with those that can afford bigger fabrication tolerances and result in a higher yield. It should be noted that the creation of the optical stack in an image sensor happens at the back-end of line (later stages of the image sensor production line). Therefore, errors in this part of the process are costlier.

For solving the crosstalk issue and bypassing the pixel size shrinkage limit, several techniques have been developed.

Indeed, for overcoming the pixel size shrinkage limit, on-chip optics in image sensors are evolved to realize the possibility for pixel shrinkage (width). However, the trend for smaller

pixel sizes in the image sensor is slowed down showing the need for new solutions in the on-chip optics. Currently, the optical stack in the image sensor consists of a microlens for light collection and a color filtering layer (as depicted in Figure 1) having a total thickness of approximately 1.5 µm.

It should be noted that solutions for reducing the crosstalk effect are much more numerous. This is due to the fact that the crosstalk effect has several sources. It can be of spectral, optical (before electron hole generation), or electrical (after electron hole generation) nature, or a combination of the above. An accepted point is that to suppress crosstalk in the image sensor, the thickness of the pixels should be minimized. Optical stack is one part that contributes to the thickness of the pixels and so increases the risk for crosstalk. The optical stack in the current image sensors include two main layers: a microlens layer and a color filter layer, together with possible buffer and matching layers in between or before and/or after. Currently the optical stack has a typical minimum thickness of 1.5 µm. However, in the absence of methods to reduce the thickness of the pixel, other solution for suppressing crosstalk has been used, including optical and electrical isolations techniques, which are applied in different parts of the structure between pixels in the image sensor.

Some usual practices for isolation between pixels for crosstalk reduction rely on the use of trenches and/or metal grid apertures.

For example, concerning the use of trenches, in BSI ("Back Side illuminated") structures, Deep Trench Insulation (DTI) or full DTI techniques are introduced mostly in the bulk of silicon for electrical and optical isolation purposes (see document **US20090200625A1** and document **US20060180885A1**). However, those trenches cannot prevent crosstalk fully as crosstalk can still happen in the optical stack including the light collection layer (microlenses) and color filtering layer. In current small pixel image sensors with pixel sizes (width) around 1.1 µm, the optical stack (microlens plus color filter layer) has still a thickness about 1.5 µm, which makes the design prone to crosstalk in the optical stack layer.

Another practiced solution for reducing crosstalk relies on the use of metal grid apertures for each pixel (see document **US8940574B2**). However, metal grids absorb and

scatter the incident light, which reduces the efficiency (in term of light acquisition) and cannot provide an efficient optical insulation between the pixels in the optical stack.

Hence, there is a need for a technique that can address these issues.

Summary of the disclosure

References in the specification to "one embodiment", "an embodiment", "an example embodiment", indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

The present disclosure is directed to an image sensor comprising a set of pixels. Each pixel of the set comprises a first and a second element, the first element comprising a photodiode module unit, and the second element being an element for filtering color and focusing incident light into said first element. The image sensor comprises at least two consecutive pixels from the set of pixels, for which first elements are put side by side, and wherein the image sensor comprises a gap between second elements of said at least two consecutive pixels.

Hence, according to one embodiment of the disclosure, it is proposed to replace the use of the micro lenses and the color filter layer in the architecture of pixels in an image sensor by a structure that achieve the both functions (focusing/guiding of light and the color filtering). In one embodiment of the disclosure, the structures described in PCT patent applications **PCT/EP2017/057129** and **PCT/EP17/057131** can be used for the choice of the second element, with added color dyes for achieving the color filtering function.

In addition, according to one embodiment of the disclosure, due to the dimensions of the second element, a pixel according to one embodiment of the disclosure has a thinner optical stack.

In one embodiment, the optical stack is implemented using the current image sensor fabrication processes and materials, but the realization of the classical microlens layer and the color filter layer is avoided. Instead, the lithography masks in the realization of the color filter layer are adapted into the design of a second element, and the proper spacing or gap between them is done. Therefore, the color filter functionality and the focusing effect functionality are obtained via a unique element, and not a plurality of elements as in the prior art. Therefore, from a manufacturing point of view, it is easier to fabricate such second element. In addition, it reduces the risk of defects in the manufacturing process.

In another entity, the spacing or gap between the second elements can be filled with a low refractive index dielectric.

In another embodiment, the second elements are implemented using high refractive index dielectric polymer, which contains dye or pigment with proper color properties. Separate lithography steps are used to fabricate each subset of the second elements (one subset for each color).

In another embodiment, the size (width) of the second element is optimized for the wavelength of the only one color it transmits.

In a preferred embodiment, each second element of the image sensor is made of a dielectric material with a complex refractive index of the form of $n + jk$, which is wavelength dependent.

In a preferred embodiment, each second element substantially only transmits one color among the red, green and blue colors.

In a preferred embodiment, each second element has a height which is defined according to the color it transmits, and dispersion properties of the material of the second element.

In a preferred embodiment, each first element is positioned on a planar layer.

In a preferred embodiment, each first element is positioned on a curved layer. Therefore, we can use a curved image sensor according to one embodiment of the disclosure.

In a preferred embodiment, the gap has a size up to 700 nm.

In a preferred embodiment, each of the second element comprises a dielectric structure comprising color absorptive dyes that have dispersive properties in a wavelength of interest.

In a preferred embodiment, the dielectric structure has a shape that belongs to a group of shapes comprising:

- a cylinder;
- a cuboid;
- a prism;
- a truncated pyramid;
- a truncated cone.

In a preferred embodiment, the image sensor is remarkable in that the width of the photodiode module unit is around 1 000 nm, and the height of a second element is around $h_r = 700\ nm$, in the case the second element substantially only transmits the red color, or is around $h_g = 1300\ nm$ in the case the second element substantially only transmits the green color or is around $h_b = 1500\ nm$ in the case the second element substantially only transmits the blue color. In addition, each second element is made of a dielectric material with a complex refractive index of the form of $n + jk$, a value of n and k being selected from the following table:

n (real part of the complex refractive	k (imaginary part of the complex refractive

index of a second element)	index of a second element)
1.4	0.009
1.27	0.053
1.4	0.073
1.72	0.185
1.65	0.004
1.53	0.079
1.63	0.265
1.82	0.158
1.7	0.028
4.61	0.185
4.08	0.110
3.78	0.095
2.04	0

In a preferred embodiment, the image sensor is remarkable in that a width of a second element is comprised between $700\ nm$ to $850\ nm$.

In a preferred embodiment, the said second elements of said at least two consecutive pixels are at least partially put side by side.

Brief description of the drawings

The above and other aspects of the invention will become more apparent by the following detailed description of exemplary embodiments thereof with reference to the attached drawings in which:

- **Figure 1** presents in a schematic way, a cross-section view of several pixels in an image sensor, according to the prior art;
- **Figure 2** presents in a schematic way, a cross-section view of several pixels in an image sensor, according to one embodiment of the disclosure;
- **Figure 3** presents in a schematic way, a cross-section view of one pixel according to one embodiment of the disclosure;
- **Figure 4(a)** presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a line l_1 positioned at the level of the interface between a first element (the photodiode unit) and the second element (corresponding

to the light focusing and color filtering element), and where the width W_{cf} of the second element is equal to $700\ nm$;

- **Figure 4(b)** presents the power value that reaches the first element, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form *1.5+jk*), with *k* equals to either 0.01 or 0.02 or 0.04, or 0.08, or 0.16, or 0.32;
- **Figure 4(c)** presents the power value that reaches the first element, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form *1.5+jk*) with *k* equals to either 0.62 or 1.26 or 2.51, or 5;
- **Figure 5(a)** presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a first line l_1 located at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), and also defines a second line l_2 located at the level of the top surface of the second element, and where the width W_{cf} of the second element is equal to $700\ nm$;
- **Figure 5(b)** presents the values of ratio of power in the corresponding points of l_1 and l_2, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.01 or 0.0397897 or 0.0793701, or 0.158322;
- **Figure 5(c)** presents the ratio of power values in the corresponding points of l_1 and l_2 for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.315811 or 1.25661 or 2.5066, or 5;
- **Figure 6** presents the link between the value of k (partially defining the refractive index of the second element) and the power loss from the second element, according to one embodiment of the disclosure when the parameter W_{cf}, defining the width of the second element, is equal to $700\ nm$;

- **Figure 7** presents the power flow in a pixel structure according to one embodiment of the disclosure, that is illumined by two kinds of electromagnetic waves;
- **Figure 8(a)** presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a line l_1 positioned at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), and where the width W_{cf} of the second element is equal to $850\ nm$;
- **Figure 8(b)** presents the power value that reaches the first element, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$), with k equals to either 0.01 or 0.02 or 0.04, or 0.08, or 0.16, or 0.32;
- **Figure 8(c)** presents the power value that reaches the first element, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.62 or 1.26 or 2.51, or 5;
- **Figure 9(a)** presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a first line l_1 located at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), the first line l_1 comprising a set of points mentioned as P_1, and also defines a second line l_2 located at the level of the top surface of the second element, the second line l_2 comprising a set of points mentioned as P_0;
- **Figure 9(b)** presents the values of ratio of power in the corresponding points of l_1 and l_2, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.01 or 0.0397897 or 0.0793701, or 0.158322;
- **Figure 9(c)** presents the values of ratio of power in the corresponding points of l_1 and l_2, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of

the focusing element (of the form $1.5 + jk$) with k equals to either 0.315811 or 1.25661 or 2.5066, or 5;

- **Figure 10** presents the link between the value of k (partially defining the refractive index of the second element) and the power loss from the second element, according to one embodiment of the disclosure, when the parameter W_{cf}, defining the width of the second element, is equal to $850\ nm$;
- **Figure 11(a)** presents the repartition of the power value that reaches the first element of a pixel according to one embodiment of the disclosure, along a line positioned at the interface level with the second element, for an incident wavelength $\lambda = 530\ nm$, for different values of the width W_p of the first element and different values of the width W_{cf} of the second element, with a refractive index of the second element being equal to 1.5 (i.e. k equals to 0);
- **Figure 11(b)** presents the repartition of the power value that reaches the first element of a pixel according to one embodiment of the disclosure, along a line positioned at the interface level with the second element, for an incident wavelength $\lambda = 530\ nm$, for different values of the width W_p of the first element and different values of the width W_{cf} of the second element, with a refractive index of the second element being equal to $1.5 + j * 0.32$ (i.e. k equals to 0.32);
- **Figure 11(c)** illustrates the difference of size between the width of the first element and the width of the second element;
- **Figure 12** presents several pixels according to one embodiment of the disclosure, wherein the width of the second elements and the refractive indexes of the second elements are defined according to the color they transmit;
- **Figure 13** presents a comparison of the power flow between conventional pixels and pixels according to one embodiment of the disclosure;
- **Figure 14** presents another embodiment of the disclosure for which the height of the second elements in a pixel is defined according to the colors it can filter;
- **Figure 15** presents another embodiment of the disclosure for which the width and the height of the second elements in a pixel are defined according to the colors it can filter;

- **Figure 16** presents an optimization process that improves the spectral crosstalk;
- **Figure 17** presents another embodiment of the disclosure, wherein the second elements of pixels are partially put side by side, and a gap is still present.

Detailed description

Figure 1 presents in a schematic way, a cross-section view of several pixels in an image sensor, according to the prior art.

Indeed, conventional pixels usually comprise an optical stack that consist of a microlens and a color filter, that are distinct parts of the optical stack. In addition, conventional pixels also comprise a photodiode unit, which is positioned below the color filter.

Figure 2 presents in a schematic way, a cross-section view of several pixels in an image sensor, according to one embodiment of the disclosure.

According to one embodiment of the disclosure, it is proposed a specific pixel structure for which the optical stack of conventional pixels is replaced by an element that can achieve both the focusing functionality and the color filtering functionality. Such element is made of a dielectric material, and the refractive index of this dielectric element is dependent of the color filtering functionality. Some examples of these dielectric elements (that do not implement the color filtering functionality) are described in the PCT patent applications **PCT/EP2017/057129** and **PCT/EP17/057131**. Hence, such embodiment of the disclosure can reduce the size of the optical stack as described later in this document.

More precisely, according to one embodiment of the disclosure, each pixel comprises a first element (the photodiode unit) and a second element (that can both focus and filter incident light). For example, the second element referenced 201 can focus incident light and substantially only transmits red light. The second element referenced 202 can focus incident light and substantially only transmits green light. At last, the second element referenced 203 can focus incident light and substantially only transmits blue light.

In another embodiment of the disclosure, a second element substantially only transmits either one of the following colors: cyan, magenta, yellow. In another embodiment, the image sensor according to the present disclosure also comprise white pixels. In another embodiment of the disclosure, it is proposed a second element that has filtering properties in other color channels used in image sensor devices.

Figure 3 presents in a schematic way, a cross-section view of one pixel according to one embodiment of the disclosure.

According to one embodiment of the disclosure, a pixel comprises a first element, which is the photodiode unit, that has a width which is noted W_p, and also comprises a second element (i.e. the focusing and color filtering element) that can be viewed as a kind of cuboid, that has a height (i.e. a thickness) noted H, and a width noted W_{cf}. Such second element is made of a dielectric material that has a complex refractive index value of the form $n + jk$, where the parameter n corresponds to the real part of the complex refractive index value, and the parameter k corresponds to the imaginary part of the complex refractive index value, which is wavelength dependent. Therefore, the second element provides high absorption for the desired wavelengths. The gap between two second elements of two consecutive pixels according to one embodiment of the disclosure, prevents leakage of light through the optical stack. In one embodiment of the disclosure, it is proposed an image sensor comprising pixels as the one depicted in Figure 3, that are arranged periodically.

Figure 4(a) presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a line l_1 positioned at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), and where the width W_{cf} of the second element is equal to $700\ nm$.

Figure 4(b) presents the power value repartition, along the line l_1, resulting from the incidence of an electromagnetic wave with a wavelength $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + j * k$), with k equal to either

0.01 or 0.02 or 0.04, or 0.08, or 0.16, or 0.32. It appears that the smaller the parameter k is, the higher the power intensity is at the center of the interface level.

Figure 4(c) presents the power value repartition, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + j * k$) with k equals to either 0.62 or 1.26 or 2.51, or 5. It appears that the when the parameter k is high, the power intensity is higher at the interface level, but outside the second element.

Figure 5(a) presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a first line l_1 located at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), and also defines a second line l_2 located at the level of the top surface of the second element, and where the width W_{cf} of the second element is equal to $700\ nm$.

It should be noted that the first element has a width W_p equal to $1\ 000\ nm$, and the second element has a height H equal to $700\ nm$. Furthermore, the second element has a complex refractive index of the form $1.5 + j * k$.

Figure 5(b) presents the values of ratio of power in the corresponding points of l_1 and l_2, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.01 or 0.0397897 or 0.0793701, or 0.158322.

Figure 5(c) presents the ratio of power values in the corresponding points of l_1 and l_2 for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.315811 or 1.25661 or 2.5066, or 5.

Figure 6 presents the link between the value of k (partially defining the refractive index of the second element) and the power loss from the second element, according to one

embodiment of the disclosure when the parameter W_{cf}, defining the width of the second element, is equal to $700\ nm$. More precisely, Figure 6 shows the total optical loss (power absorption) in the color filter for different values of parameter k. We can see that there is a point ($k = 0.32$) with maximum loss (absorption) in the color filter, which gives a minimum level of leakage (see Figure 4(b) for $= 0.32$) as well, which is the desired behavior for a color filter element.

Figure 7 presents the power flow in a pixel structure according to one embodiment of the disclosure, that is illumined by two kinds of electromagnetic waves (i.e. TE (transverse-electric) and TM (transverse-magnetic) electromagnetic waves).

Here, a 2D model is considered with the structure being infinite along y-axis.

More precisely, Figure 7 shows the power flow in a pixel structure with cuboid lens-color-filter element, for both TE and TM polarizations. The figure shows that the focusing effect is valid for both polarization conditions.

Figure 8(a) presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a line l_1 positioned at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), and where the width W_{cf} of the second element is equal to $850\ nm$.

It should be noted that the first element has a width W_p equal to $1\ 000\ nm$, and the second element has a height H equal to $700\ nm$. Furthermore, the second element has a complex refractive index of the form $1.5 + j * k$.

Figure 8(b) presents the power value that reaches the first element, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$), with k equals to either 0.01 or 0.02 or 0.04, or 0.08, or 0.16, or 0.32. Here again, as for the case where $W_{cf} = 700\ nm$, it appears that the smaller the parameter k is, the higher the power intensity is at the center of the interface level.

Figure 8(c) presents the power value that reaches the first element, along the line l_1, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.62 or 1.26 or 2.51, or 5.

Here again, it appears that the when the parameter k is high, the power intensity is higher at the interface level, but outside the second element.

Figure 9(a) presents a topology of a pixel according to one embodiment of the disclosure (not to scale) that defines a first line l_1 located at the level of the interface between a first element (the photodiode unit) and the second element (corresponding to the light focusing and color filtering element), and also defines a second line l_2 at the top surface of the second element.

Figure 9(b) presents the values of ratio of power in the corresponding points of l_1 and l_2, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.01 or 0.0397897 or 0.0793701, or 0.158322.

Figure 9(c) presents the values of ratio of power in the corresponding points of l_1 and l_2, for an incident wavelength of $\lambda = 530\ nm$ for different values for the refractive index of the focusing element (of the form $1.5 + jk$) with k equals to either 0.315811 or 1.25661 or 2.5066, or 5.

Figure 10 presents the link between the value of k (partially defining the refractive index of the second element) and the power loss from the second element, according to one embodiment of the disclosure, when the parameter W_{cf}, defining the width of the second element, is equal to $850\ nm$.

Here again, as for Figure 6, we can observe the total optical loss (power absorption) in the color filter for different values of parameter k. We can see that there is a point ($k = 0.32$) with maximum loss (absorption) in the color filter, which gives a minimum level of leakage (see Figure 8(b) for $= 0.32$) as well, which is the desired behavior for a color filter element.

Therefore, from the analysis of Figures 4 to 10, it appears that it can be possible to select some specific values for the refractive index, with some specific dimensions (especially for the second element) for obtaining the following properties:

- a high absorption (in term of color absorption) for the second element;
- low leakage of the incident light through the gap between the second elements;
- a focusing effect for the second element.

Figure 11(a) presents the repartition of the power value that reaches the first element of a pixel according to one embodiment of the disclosure, along a line positioned at the interface level with the second element, for an incident wavelength $\lambda = 530\ nm$, for different values of the width W_p of the first element and different values of the width W_{cf} of the second element, with a refractive index of the second element being equal to 1.5 (i.e. k equals to 0).

Figure 11(b) presents the repartition of the power value that reaches the first element of a pixel according to one embodiment of the disclosure, along a line positioned at the interface level with the second element, for an incident wavelength $\lambda = 530\ nm$, for different values of the width W_p of the first element and different values of the width W_{cf} of the second element, with a refractive index of the second element being equal to $1.5 + j * 0.32$ (i.e. k equals to 0.32).

More precisely, Figure 11(b) shows that the power is almost zero for the chosen value of k (and different values of width).

Figure 11(c) illustrates the difference of size between the width of the first element and the width of the second element.

Hence, Figures 11(a)-(c) show that the proposed technique is scalable to smaller pixel sizes (smaller that $1000\ nm$). These figures also show the high absorption properties in the second element, the low leakage that occurs outside the second element (in the gap between two consecutives second elements) and a pronounced focusing effect for pixel widths equal to $W_p = 700, 800, 900$ and $1000\ nm$, with respective to width of the second element $W_{cf} =$

$400, 500, 600$ and $700\ nm$. This shows feasibility of the present technique in the submicron pixel sizes. Other geometry combinations of the pixel size, second element width and height (thickness) can be obtained in an optimization process.

Figure 12 presents several pixels according to one embodiment of the disclosure, wherein the width of the second elements and the refractive indexes of the second elements are defined according to the color they transmit.

More precisely, in one embodiment of the disclosure, the thickness (height) of a second element for different pixels is assumed to be equal. Material properties n_i (real part of the complex refractive index of a second element), k_i(imaginary part of the complex refractive index of a second element) for i =r (red color), g (green color) and b (blue color), and Si and SiNx, which are used for implementing this model in the software CST(Computer Simulation Technologies) Studio are taken from the article entitled : "*Efficiency enhancement in a backside illuminated 1.12 μm pixel CMOS image sensor via parabolic color filters.*" by Lee, Jong-Kwon, et al., published in Optics express 24.14 (2016): 16027-16036, and are shown in the following table:

Material for second element	Wavelength (nm)	n (real part of the complex refractive index of the second element)	k (imaginary part of the complex refractive index of the second element)
B color filter	450	1.4	0.009
	530	1.27	0.053
	620	1.4	0.073
G color filter	450	1.72	0.185
	530	1.65	0.004
	620	1.53	0.079
R Color filter	450	1.63	0.265
	530	1.82	0.158
	620	1.7	0.028
Si	450	4.61	0.185
	530	4.08	0.110
	620	3.78	0.095
SiN_x	All	2.04	0

Figure 13 presents a comparison of the power flow between conventional pixels and pixels according to one embodiment of the disclosure.

More precisely, Figure 13 shows the power flow in the conventional structure and the proposed structure with similar geometrical dimensions. The incident light has 30° tilt respective to the normal. Spectral crosstalk is visible in both cases. Leakage of the power flow from one pixel to the neighboring pixel (optical crosstalk) is clearly visible in the conventional structure while the proposed structure shows a better performance.

Figure 14 presents another embodiment of the disclosure for which the height of the second elements in a pixel is defined according to the colors it can filter.

For example, in figure 14, the height of the second element referenced 140 only transmits the red color. The height of the second element referenced 141 only transmits the green color. At last, the height of the second element referenced 142 only transmits the blue color.

Figure 15 presents another embodiment of the disclosure for which the height of the second elements in a pixel are defined according to the colors it can filter.

More precisely, according to simulations, it appears that it can be interesting to design an image sensor wherein the second element of a pixel has a height which is dependent of the color filtering properties. For example, the height of a second element that can transmit only the red color is noted h_r, the height of a second element that can transmit only the green color is noted h_g and the height of a second element that can transmit only the red color is noted h_b. It should be noted that the width of the second elements affects the aperture size and focusing properties rather than the filtering functionality.

In one embodiment of the disclosure, we have the following relationship which is established: $h_b > h_g > h_r$. Other relationships can occur depending on the dispersion of the color filter materials used for different colors.

For instance, with constant values of k, one may expect the opposite relation, e.g. nearly equal height in terms of the corresponding wavelength that would lead to a smallest second element that can substantially only transmits blue color, and a largest second element that can substantially only transmits red color.

More precisely, other relationships concerning the height of the second elements can be established based on the absorption properties of the light filtering material, or for other color bands.

Figure 16 presents an optimization process that improves the spectral crosstalk.

More precisely, Figure 16 illustrates an optimization process for improving the spectral crosstalk and so the overall performance of the color filters of the second elements, by choosing the proper thickness for each color filter material. The thickness h_r is kept constant at 700 nm, while the thickness of h_g and h_b are varied between 700 to 1500 nm. A design with $h_r = 700\,nm$, $h_g = 1300\,nm$ and $h_b = 1500\,nm$ is marked in Figure 16, and such embodiment of the disclosure provides better color separation compared to other combinations, and consequently it reduced the spectral crosstalk. Some simulations have been done for red, green and blue illumination cases and each of the graphs shows the light power density that reaches to the photodiode. For example, Figure 16(a) shows the filtering performance of the red, green and blue color filters under red illumination.

Figure 17 presents another embodiment of the disclosure, wherein the second elements of pixels are partially put side by side, and a gap is still present.

It should be noted that such embodiment can also be combined with the teachings of the previous described embodiments.

Claims

1. An image sensor comprising a set of pixels, wherein each pixel of said set comprises a first and a second element, said first element comprising a photodiode module unit, and said second element being an element for filtering color and focusing incident light into said first element, and
wherein said image sensor comprises at least two consecutive pixels from said set of pixels, for which first elements are put side by side, and wherein said image sensor comprises a gap between second elements of said at least two consecutive pixels.

2. The image sensor according to claim 1, wherein each second element is made of a dielectric material with a complex refractive index of the form of $n + jk$, which is wavelength dependent.

3. The image sensor according to any claims 1 to 2, wherein each second element substantially only transmits one color among the red, green and blue colors.

4. The image sensor according to any claims 1 to 3, wherein each second element has a height which is defined according to the color it transmits, and dispersion properties of the material of the second element.

5. The image sensor according to any claims 1 to 4, wherein each first element is positioned on a planar layer.

6. The image sensor according to any claims 1 to 4, wherein each first element is positioned on a curved layer.

7. The image sensor according to any claims 1 to 6, wherein said gap has a size up to 700 nm.

8. The image sensor according to any claims 1 to 7, wherein each of said second element comprises a dielectric structure comprising color absorptive dyes that have dispersive properties in a wavelength of interest.

9. The image sensor according to claim 8, wherein said dielectric structure has a shape that belongs to a group of shapes comprising:

- a cylinder;
- a cuboid;
- a prism;
- a truncated pyramid;
- a truncated cone.

10. The image sensor according to any claims 1 to 9, wherein the width of the photodiode module unit is around 1 000 nm, and the height of a second element is around $h_r = 700\,nm$, in the case the second element substantially only transmits the red color, or is around $h_g = 1300\,nm$ in the case the second element substantially only transmits the green color or is around $h_b = 1500\,nm$ in the case the second element substantially only transmits the blue color, and wherein each second element is made of a dielectric material with a complex refractive index of the form of $n + jk$, a value of n and k being selected from the following table:

n (real part of the complex refractive index of a second element)	k (imaginary part of the complex refractive index of a second element)
1.4	0.009
1.27	0.053
1.4	0.073
1.72	0.185
1.65	0.004
1.53	0.079
1.63	0.265
1.82	0.158
1.7	0.028
4.61	0.185

4.08	0.110
3.78	0.095
2.04	0

11. The image sensor according to any claims 1 to 10, wherein a width of a second element is comprised between $700\ nm$ to $850\ nm$.

12. The image sensor according to any claims 1 to 11, wherein said second elements of said at least two consecutive pixels are at least partially put side by side.

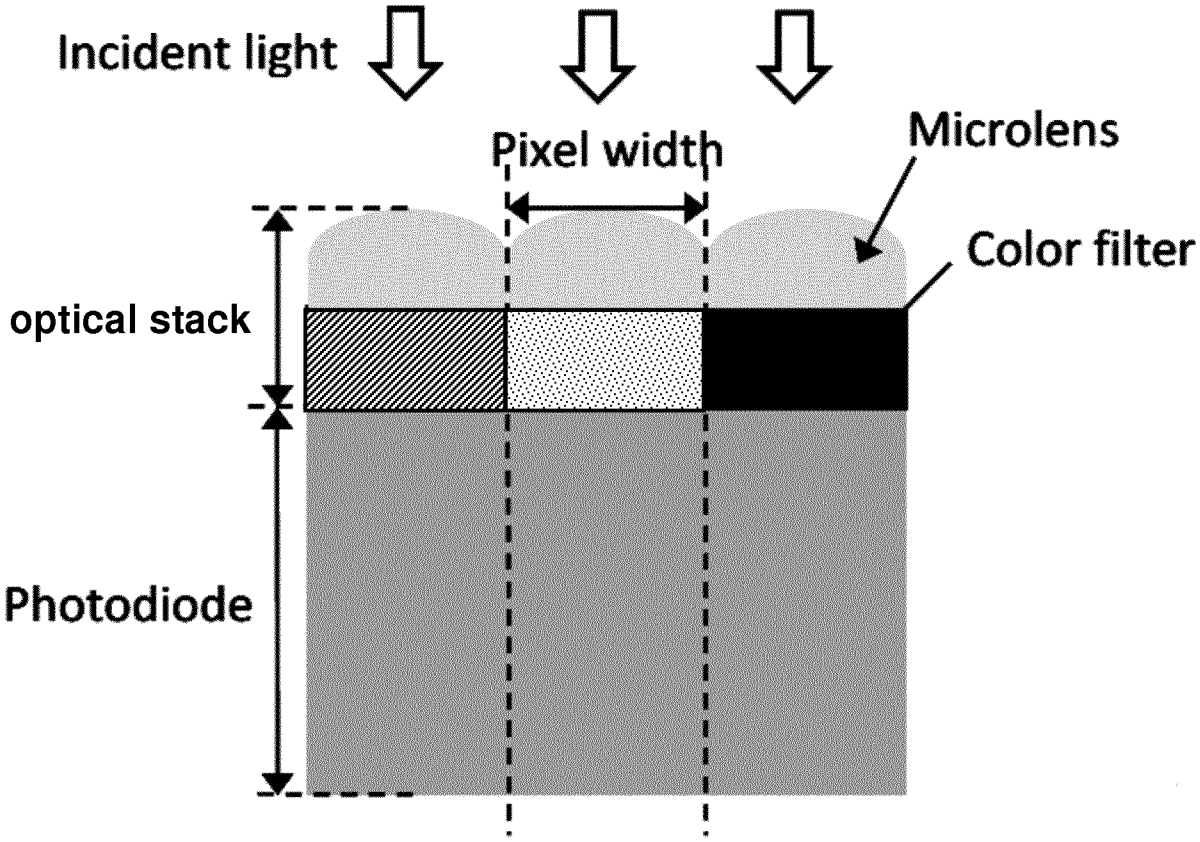

Incident light
Pixel width
Microlens
Color filter
optical stack
Photodiode

FIG.1

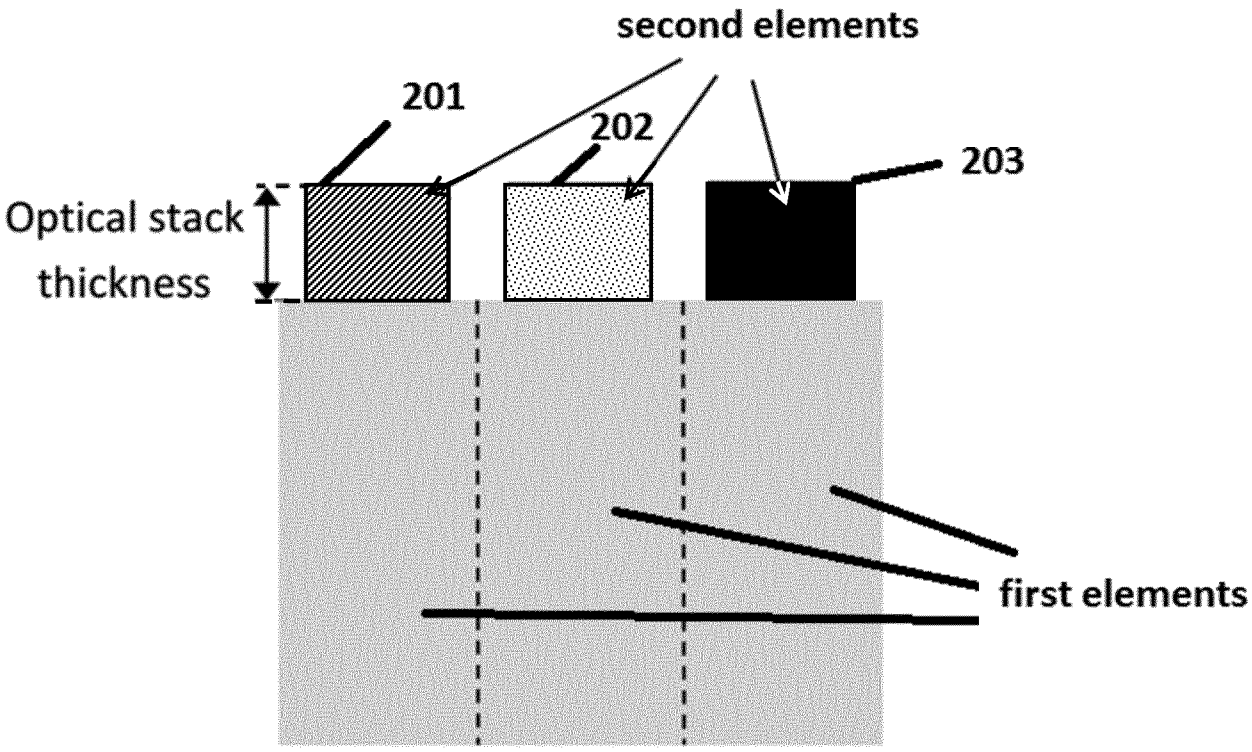

second elements
201
202
203
Optical stack thickness
first elements

FIG.2

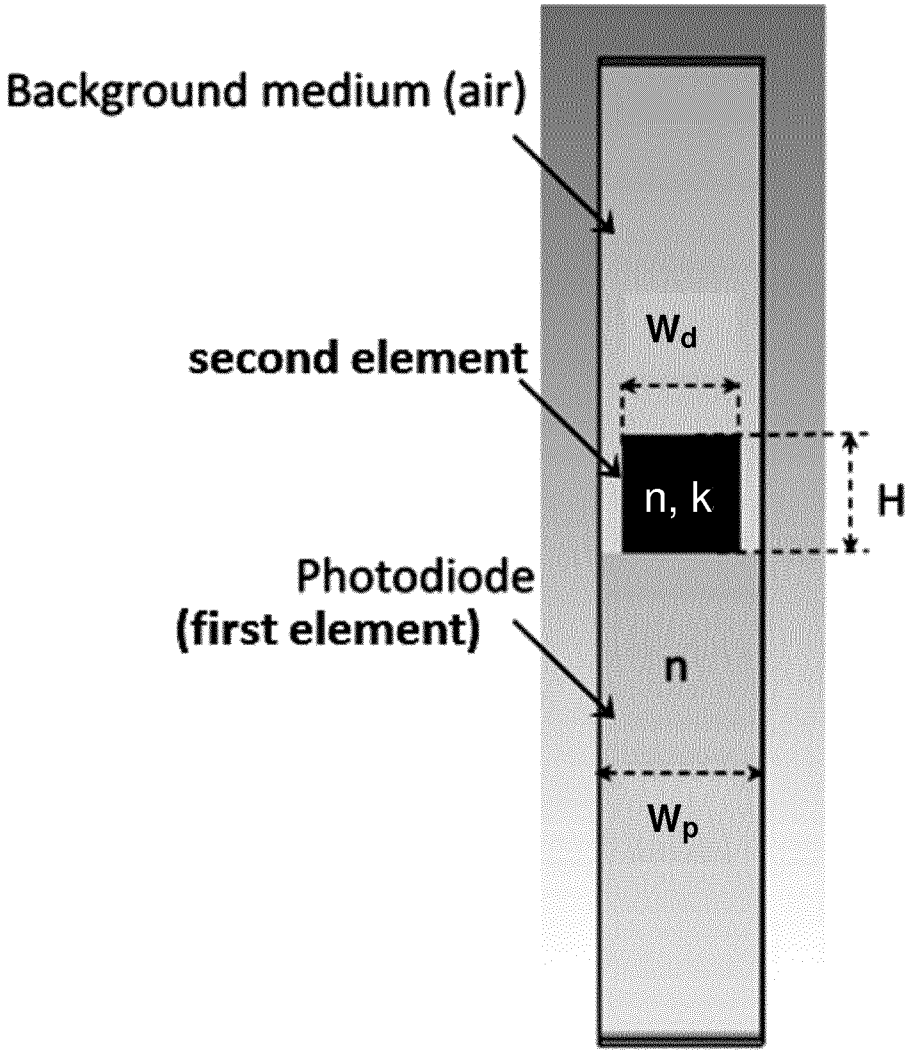

Background medium (air)
second element
Photodiode
(first element)
W_d
n, k
H
n
W_p

FIG.3

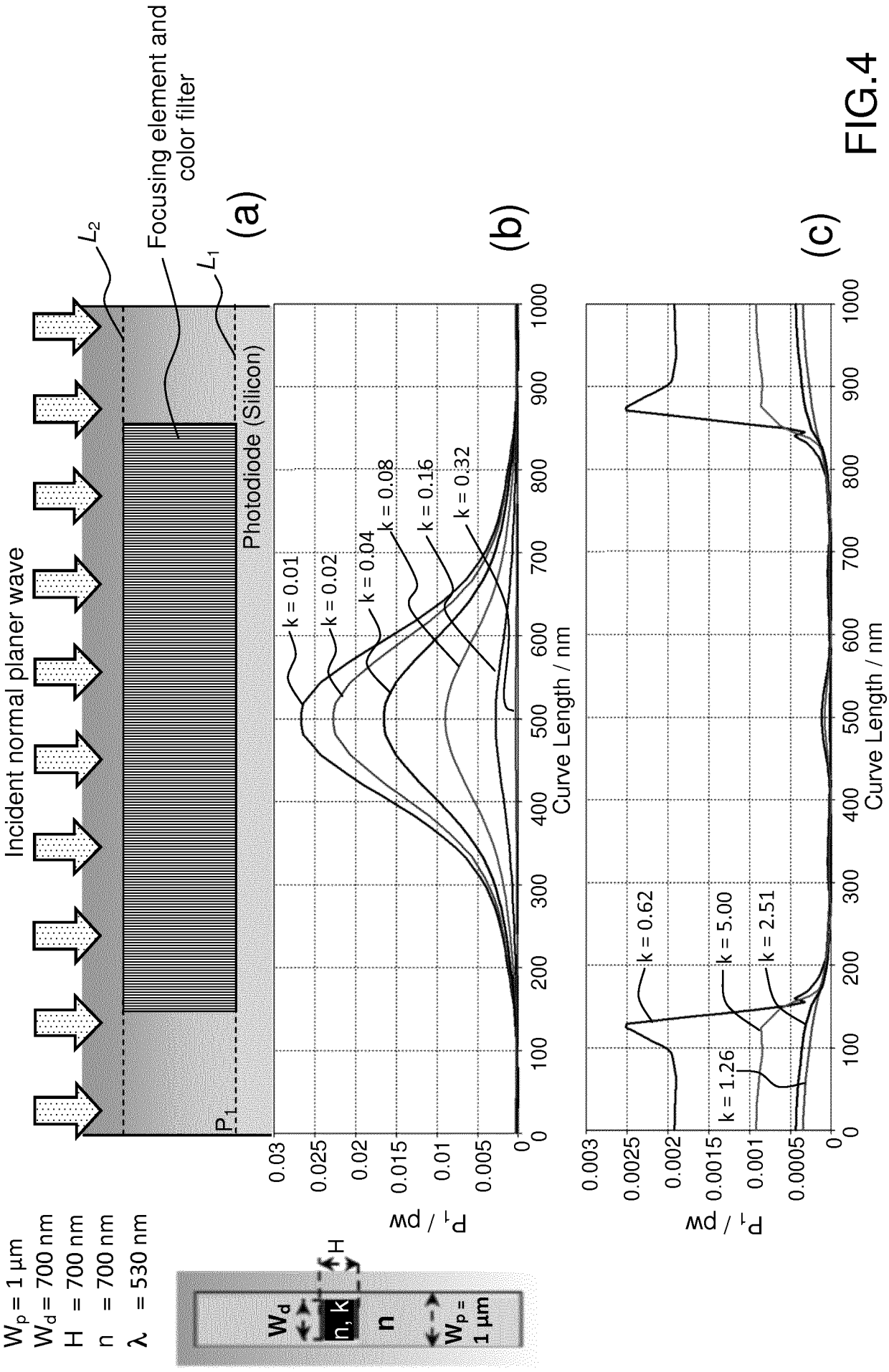

Incident normal planer wave
Focusing element and color filter
L_2
L_1
Photodiode (Silicon)
P_1
(a)
(b)
(c)
k = 0.01
k = 0.02
k = 0.04
k = 0.08
k = 0.16
k = 0.32
k = 0.62
k = 5.00
k = 2.51
k = 1.26
P_1 / pw
Curve Length / nm
W_p = 1 µm
W_d = 700 nm
H = 700 nm
n = 700 nm
λ = 530 nm
W_d
n, k
n
H
W_p = 1 µm

FIG.4

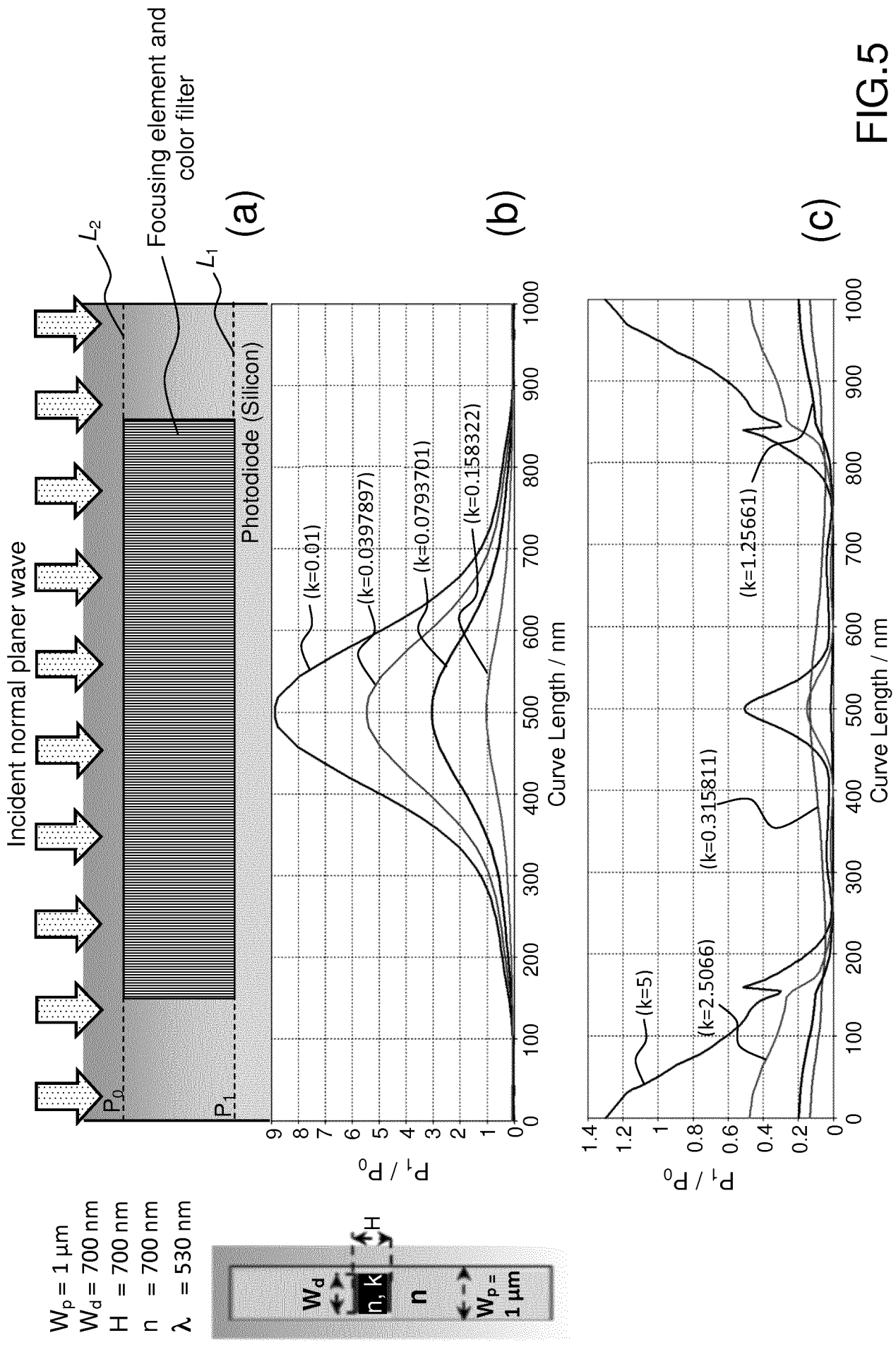
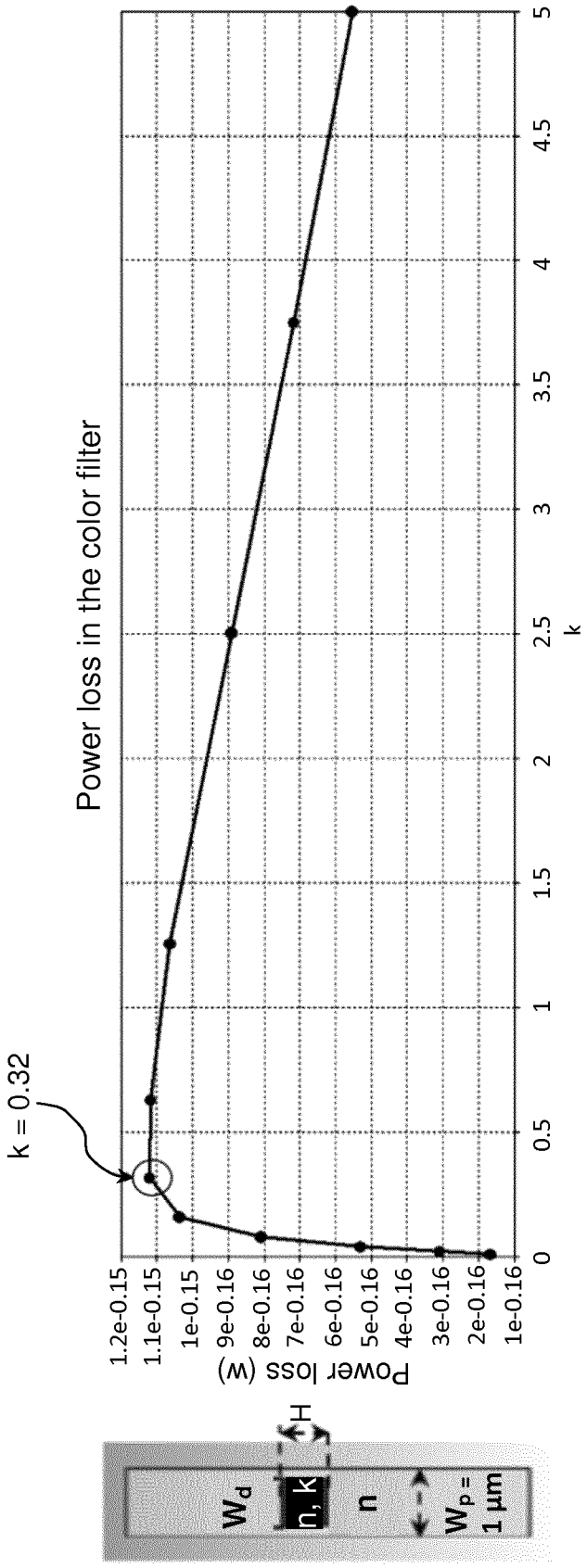

Incident normal planer wave
Focusing element and color filter
Photodiode (Silicon)
L_2
L_1
P_0
P_1
(a)
(b)
(c)
P_1 / P_0
Curve Length / nm
(k=0.01)
(k=0.0397897)
(k=0.0793701)
(k=0.158322)
(k=5)
(k=2.5066)
(k=0.315811)
(k=1.25661)
W_p = 1 µm
W_d = 700 nm
H = 700 nm
n = 700 nm
λ = 530 nm
W_d
n, k
n
H
W_p = 1 µm

FIG.5



W_p = 1 µm
W_d = 700 nm
H = 700 nm
n = 1.5
λ = 530 nm

FIG.6

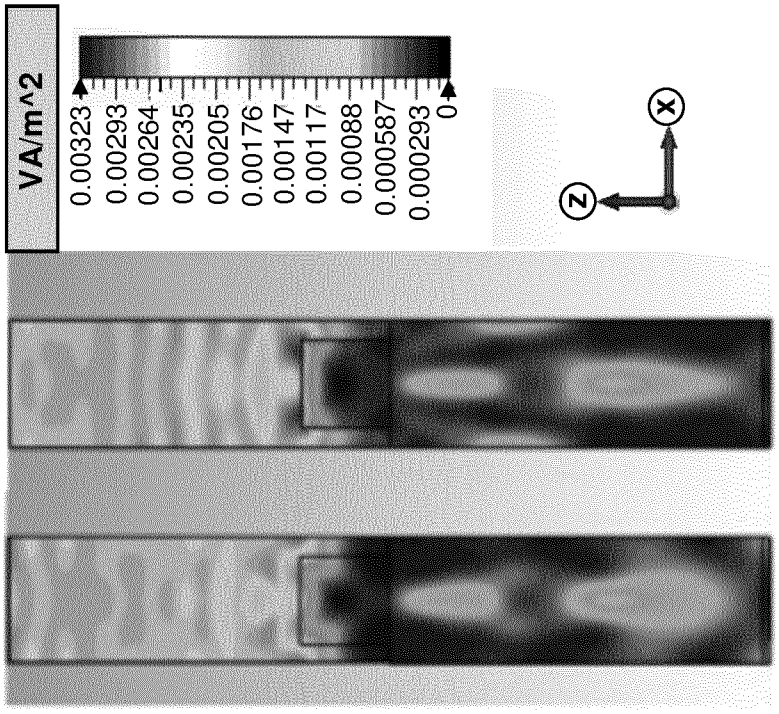

VA/m^2
0.00323
0.00293
0.00264
0.00235
0.00205
0.00176
0.00147
0.00117
0.00088
0.000587
0.000293
0
z
x
Polarization :
TE
TM
W_p = 1 µm
W_{cf} = 700 nm
H = 700 nm
n = 1.5
k = 0.32
λ = 530 nm

FIG.7

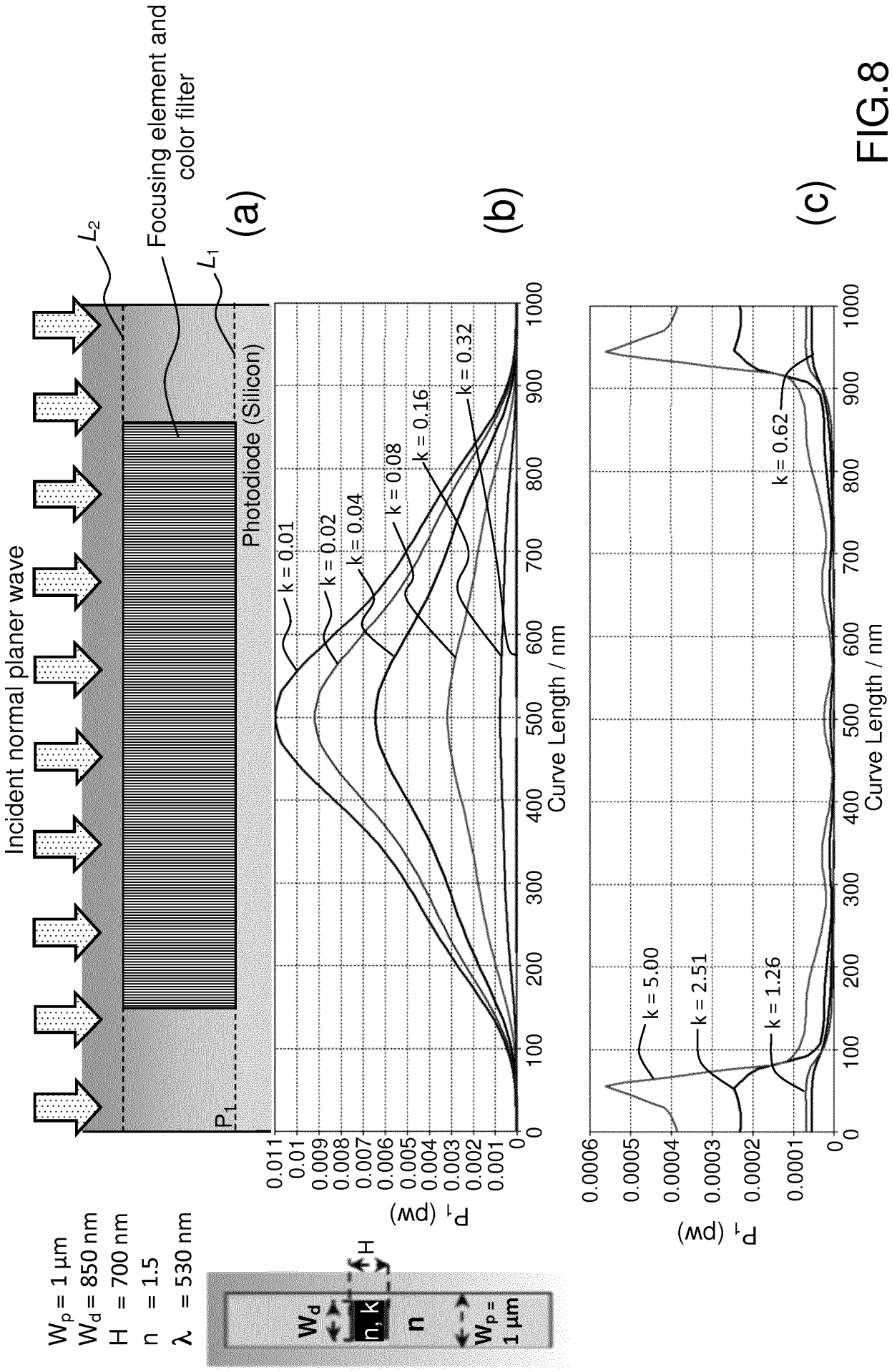

Incident normal planer wave
Focusing element and color filter
L_2
L_1
P_1
Photodiode (Silicon)
(a)
(b)
(c)
W_p = 1 μm
W_d = 850 nm
H = 700 nm
n = 1.5
λ = 530 nm
H
W_d
n, k
n
W_p = 1 μm
P_1 (pW)
Curve Length / nm
k = 0.01
k = 0.02
k = 0.04
k = 0.08
k = 0.16
k = 0.32
k = 0.62
k = 1.26
k = 2.51
k = 5.00

FIG.8

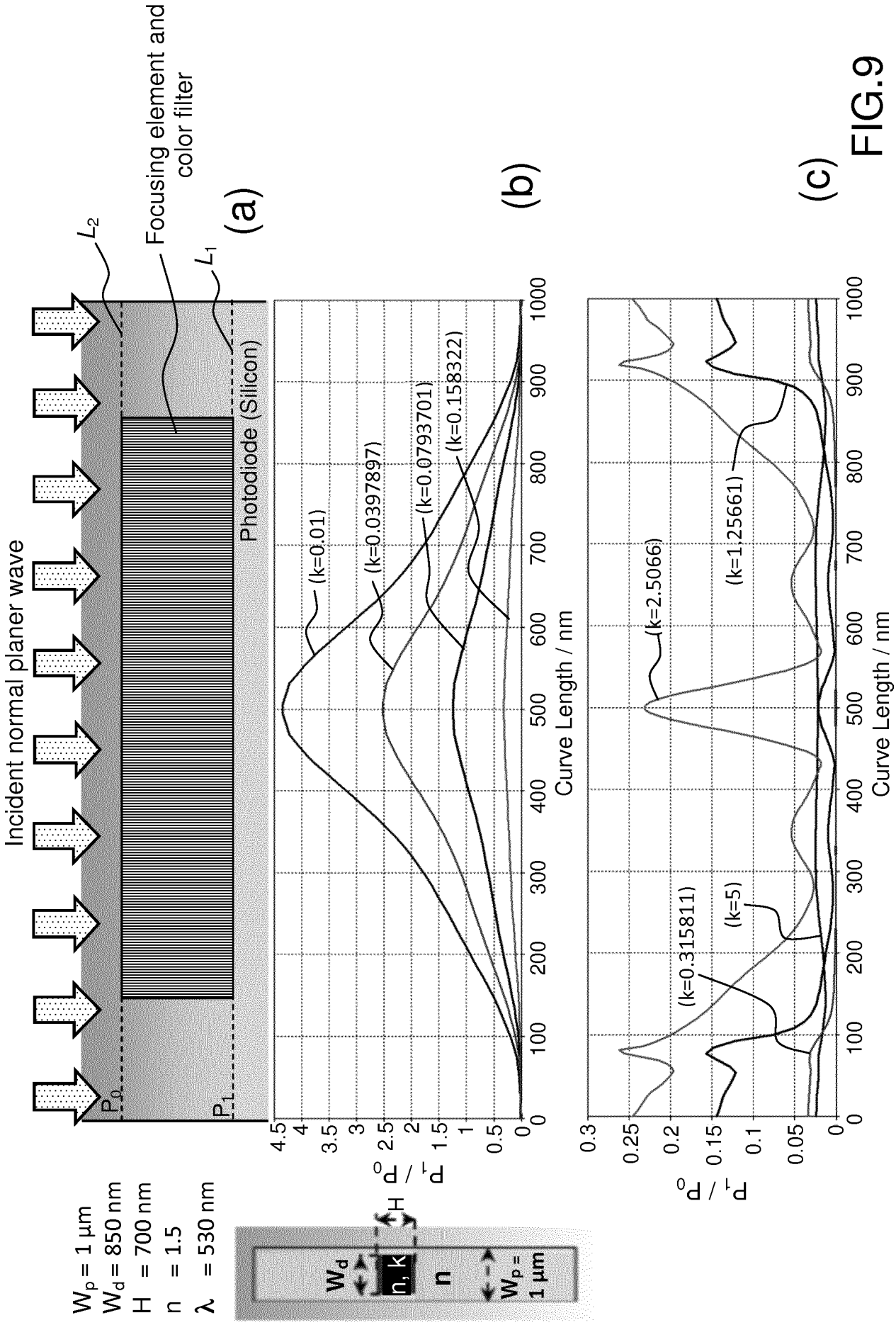

Incident normal planer wave
Focusing element and color filter
Photodiode (Silicon)
L_2
L_1
P_0
P_1
(a)
(b)
(c)
W_p = 1 μm
W_d = 850 nm
H = 700 nm
n = 1.5
λ = 530 nm
W_d
n, k
n
H
W_p = 1 μm
P_1 / P_0
Curve Length / nm
(k=0.01)
(k=0.0397897)
(k=0.0793701)
(k=0.158322)
(k=0.315811)
(k=5)
(k=2.5066)
(k=1.25661)

FIG.9

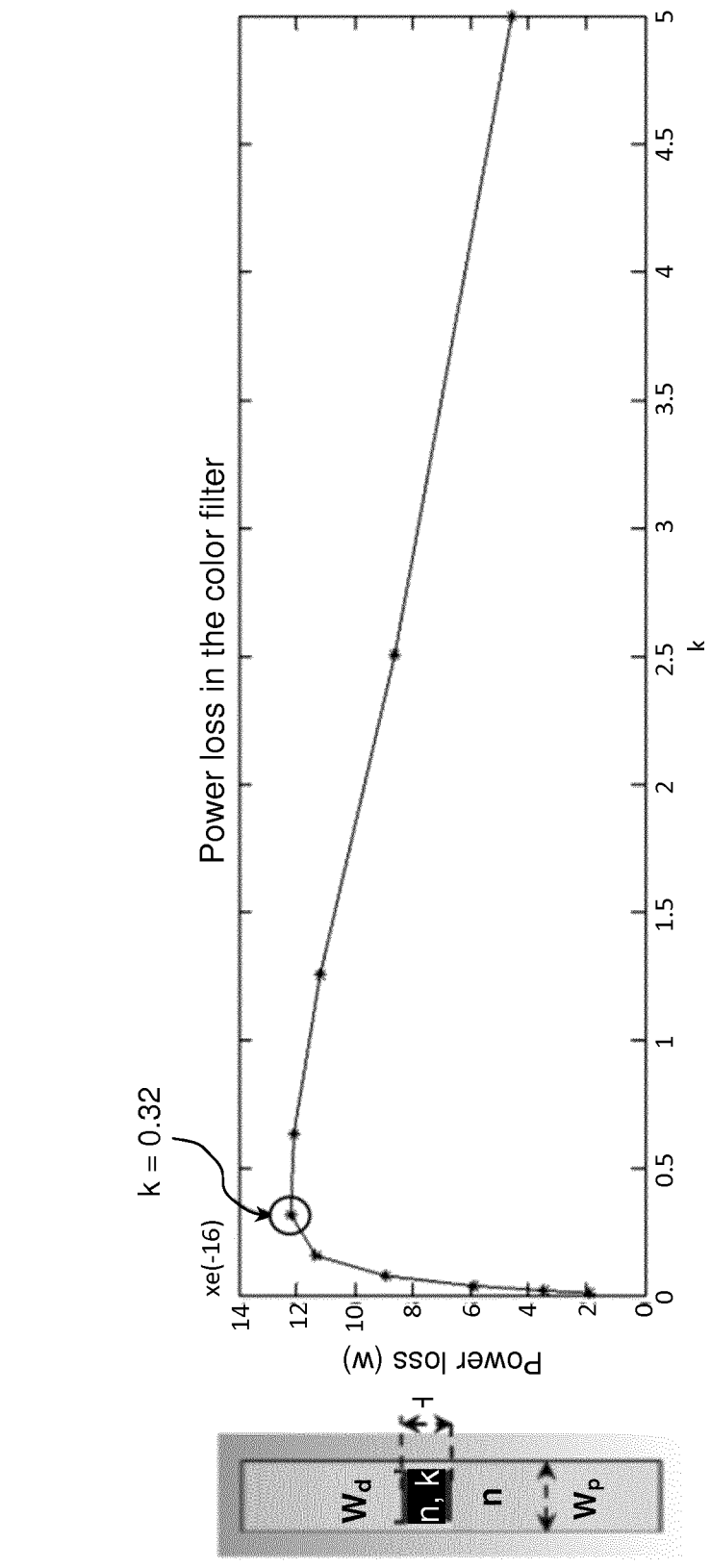
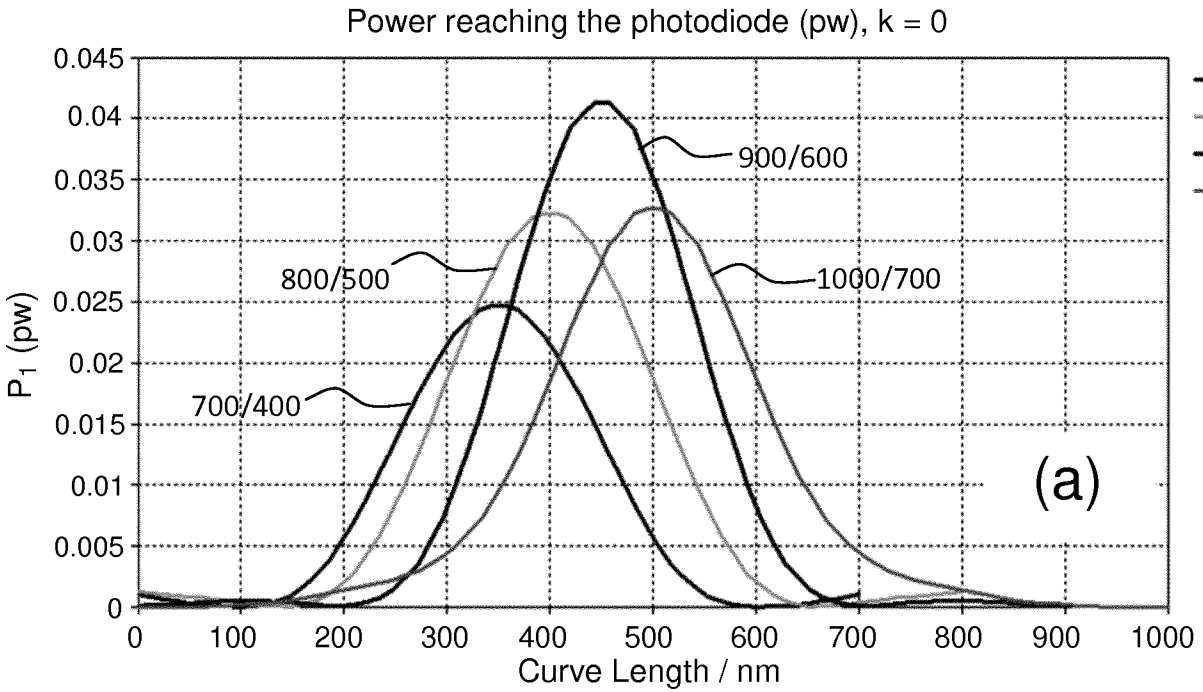
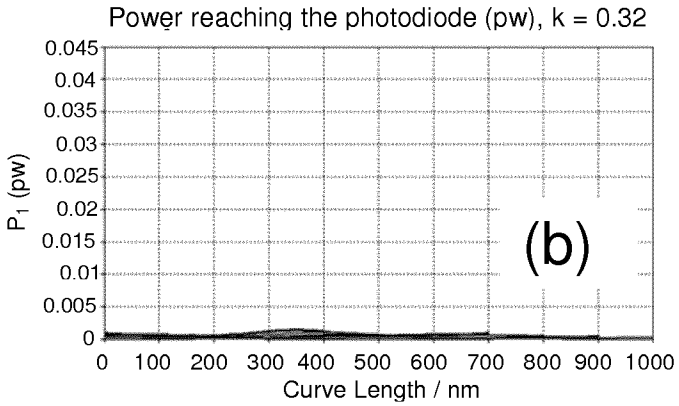
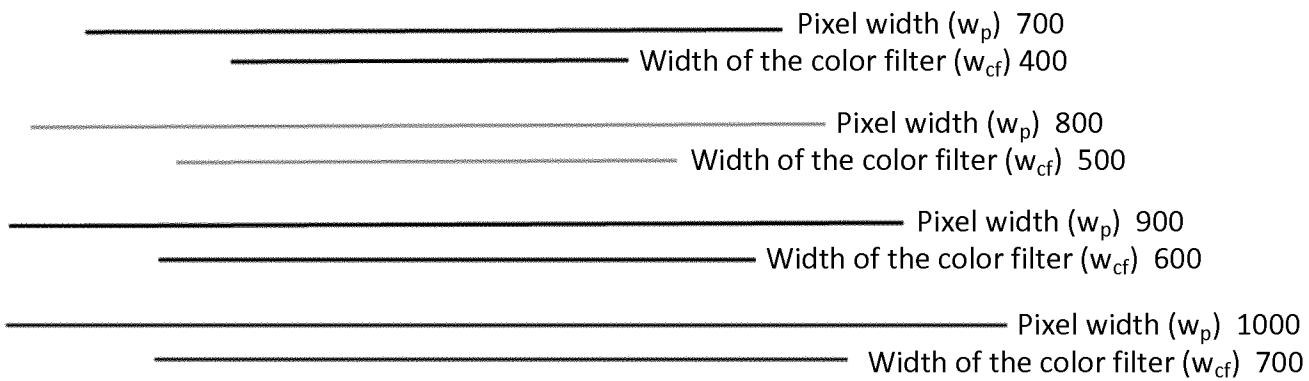

Power loss in the color filter
Power loss (W)
k
xe(-16)
k = 0.32
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
2
4
6
8
10
12
14
W_d
n, k
n
W_p
H
W_p = 1 µm
W_d = 850 nm
H = 700 nm
n = 1.5
λ = 530 nm

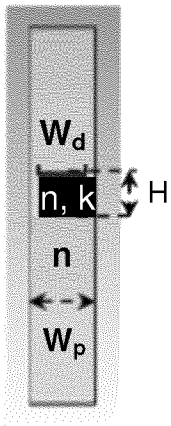
FIG.10



W_p (nm)	W_{cf} (nm)
700	400
800	500
900	600
1000	700







H = 700 nm
n = 1.5
λ = 530 nm

FIG.11

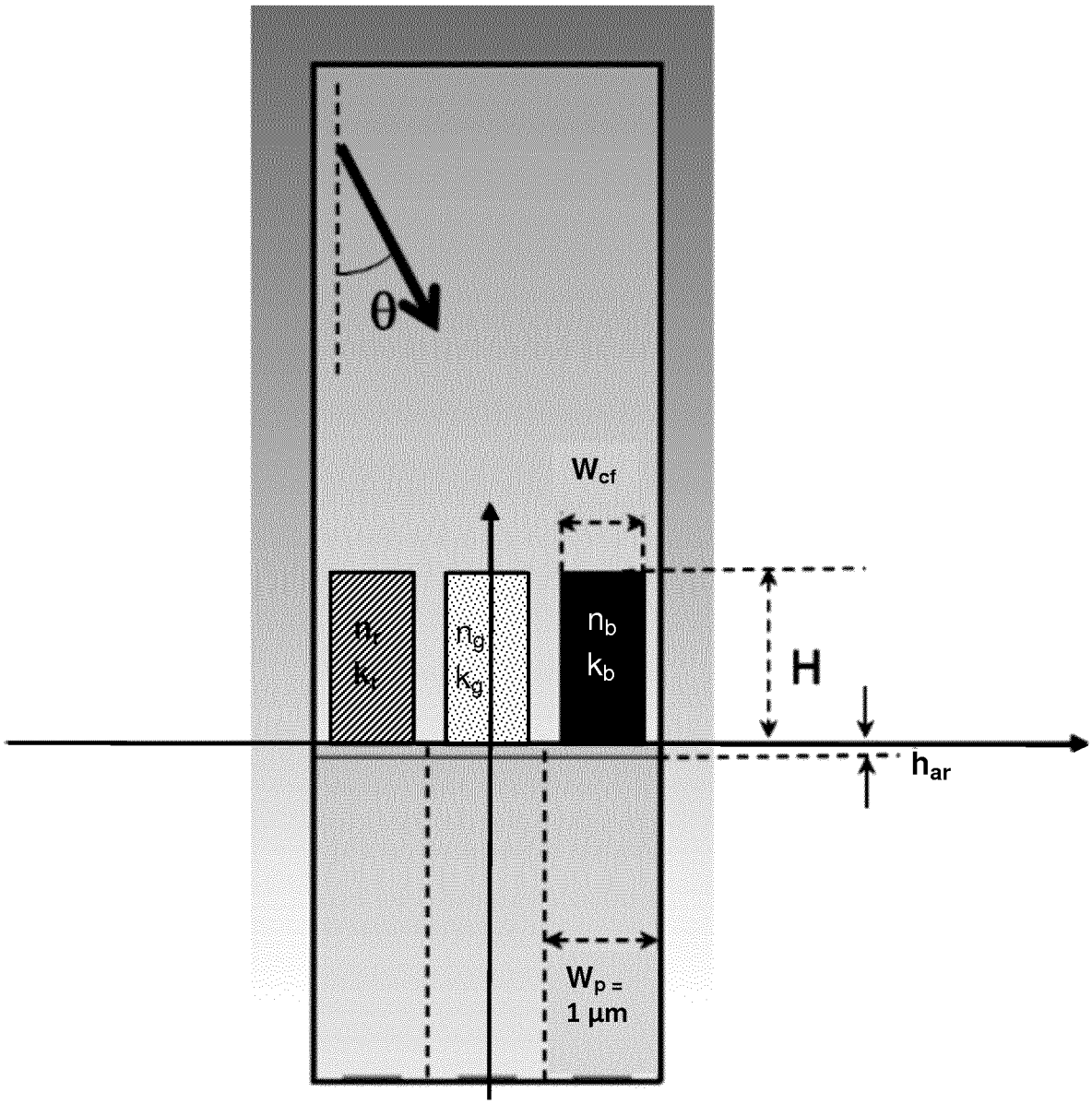


FIG.12

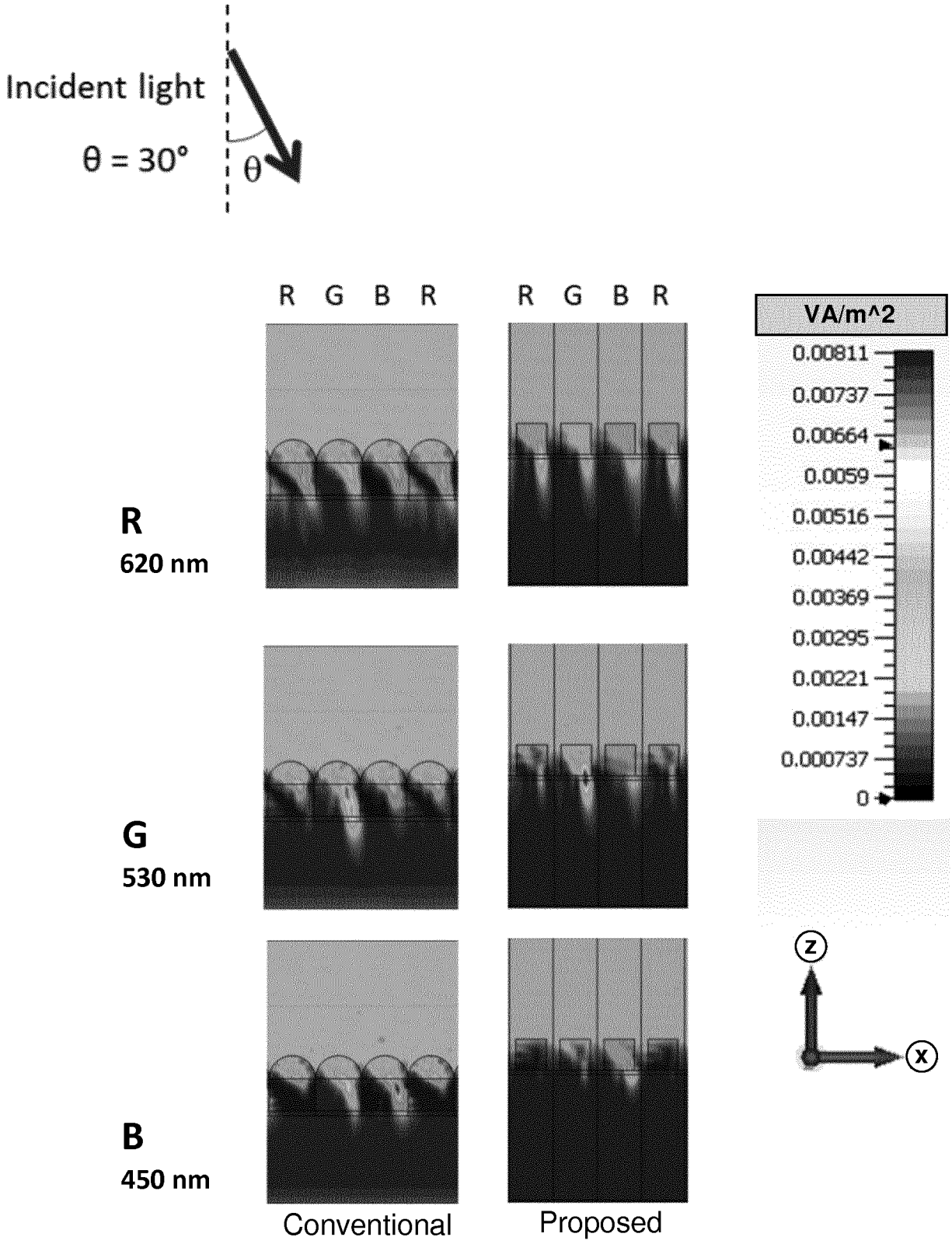

Incident light
θ = 30°
θ
R G B R
R G B R
VA/m^2
0.00811
0.00737
0.00664
0.0059
0.00516
0.00442
0.00369
0.00295
0.00221
0.00147
0.000737
0
R
620 nm
G
530 nm
B
450 nm
Z
X
Conventional
Proposed

FIG.13

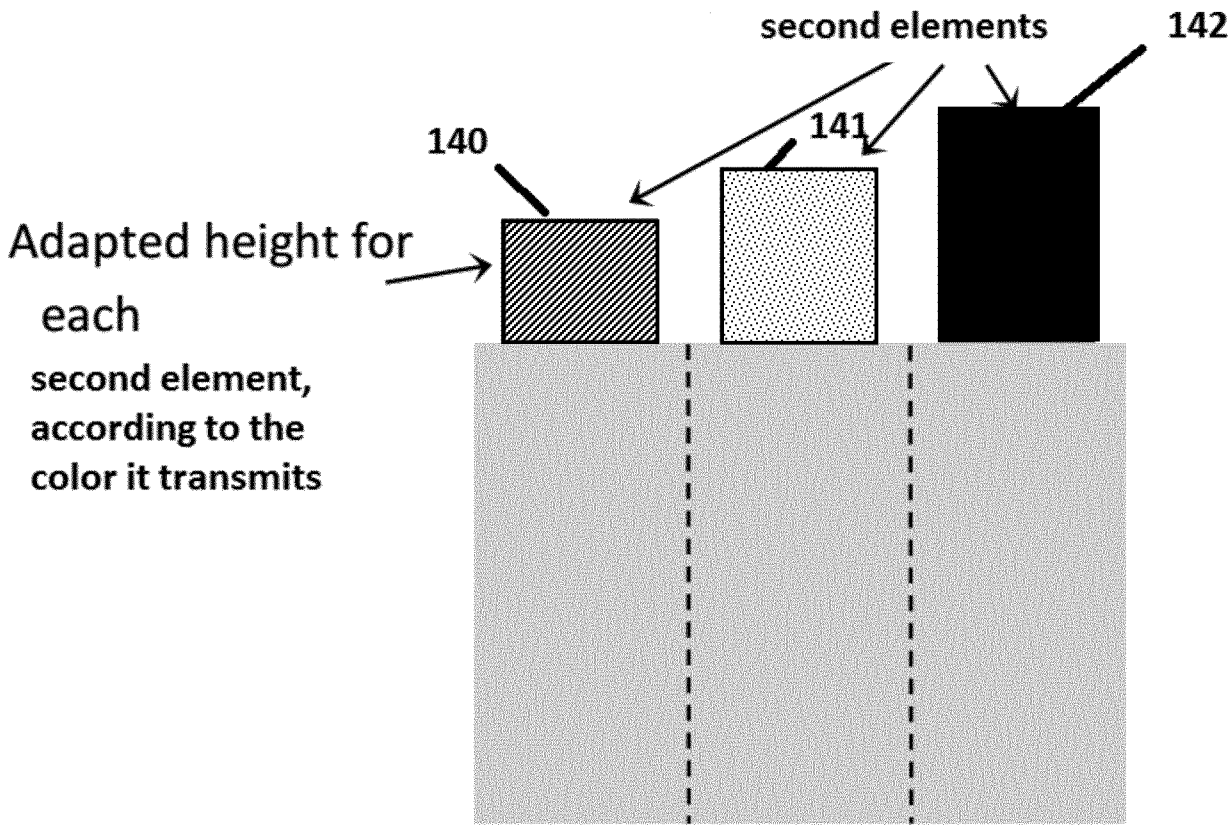

second elements
142
140
141
Adapted height for each
second element, according to the color it transmits

FIG.14

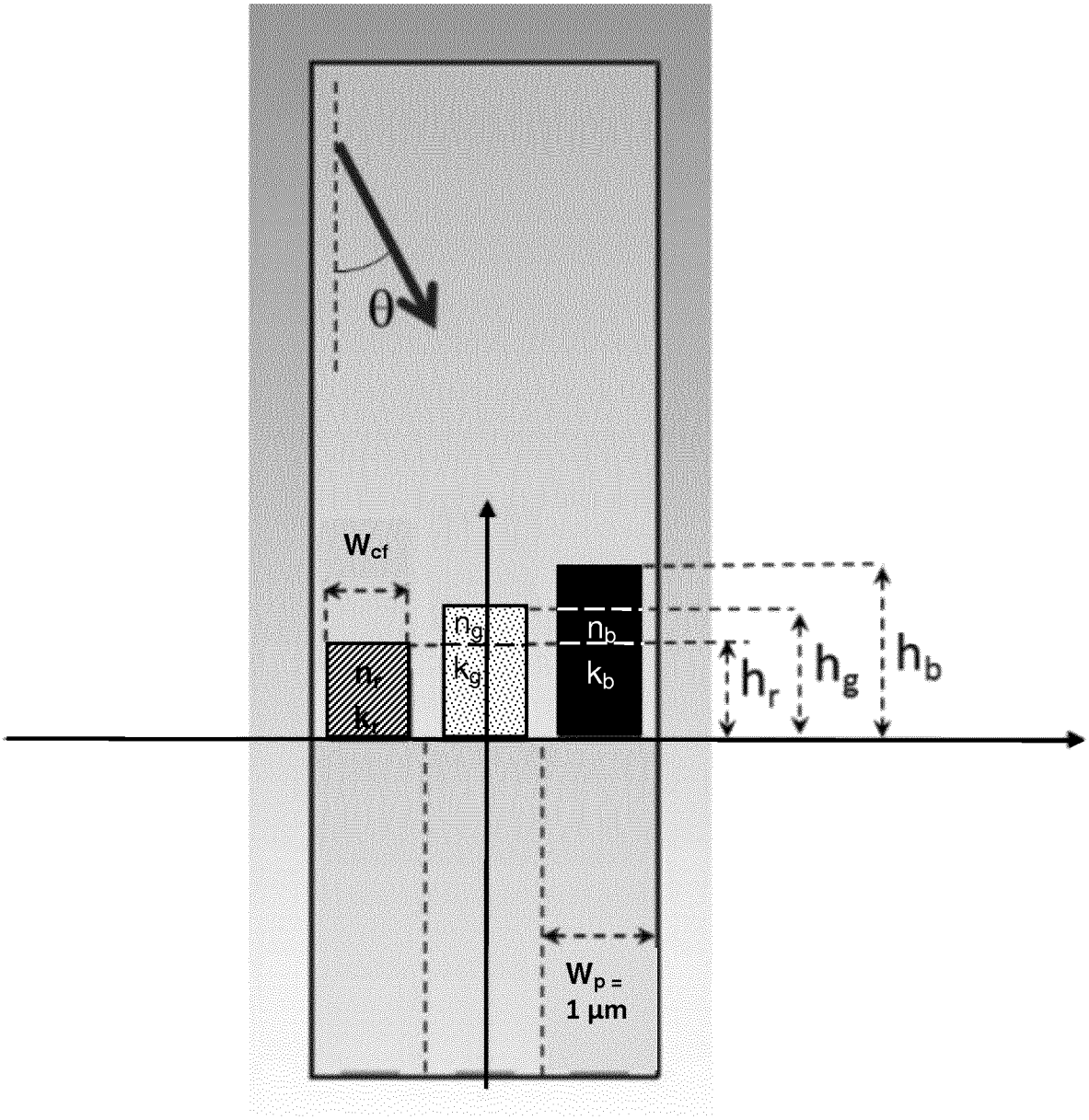


FIG.15

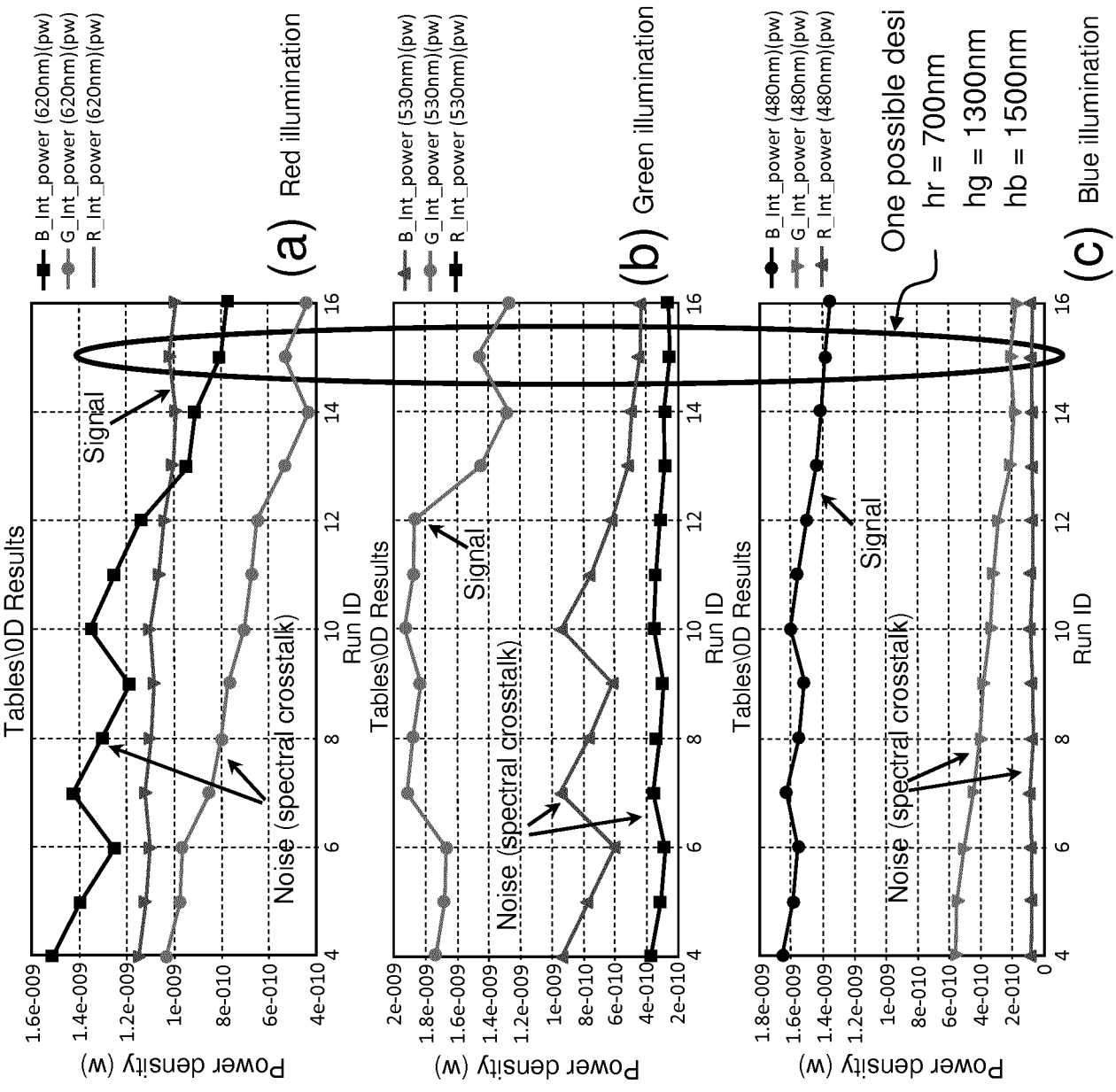


FIG.16

Normal incident
Parameter sweep

hr = 700nm
hg = 700,...,1500nm
hb = 700,...,1500nm

3D Run ID	hb	hg
9	1100	900
10	700	1100
11	900	1100
12	1100	1100
13	1300	1300
14	1300	1500
15	1500	1300
16	1500	1500

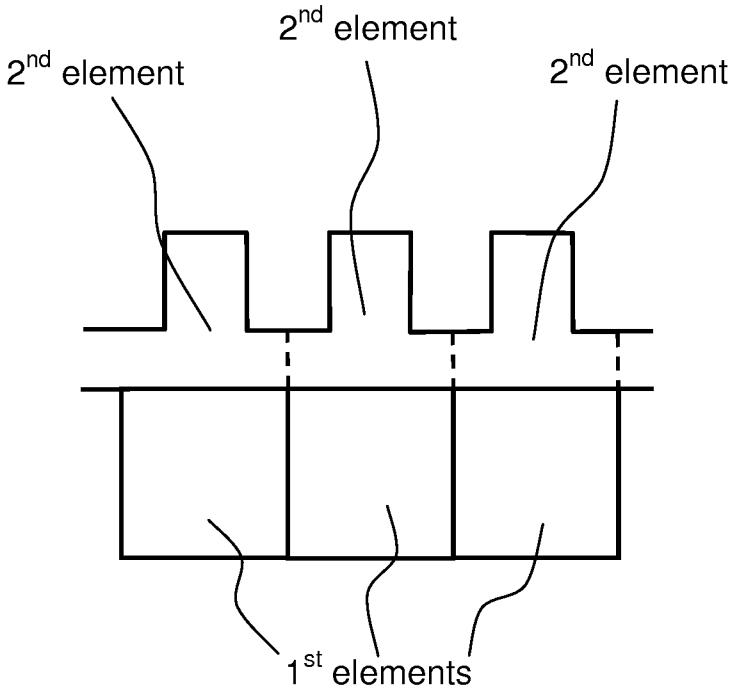


FIG.17

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/073541

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L27/146
ADD.

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

B. FIELDS SEARCHED

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/250594 A1 (TANAKA KEISUKE [JP] ET AL) 8 October 2009 (2009-10-08) paragraphs [0074] - [0084]; figures 1,3,5	1-6,8-12
X	US 2009/166518 A1 (TAY HIOK-NAM [SG] ET AL) 2 July 2009 (2009-07-02) figures 2,3A-3I, 5, 6A,6B, 7-8	1,2,5,7, 9,12
A	EP 1 414 073 A2 (HUA WEI SEMICONDUCTOR SHANGHAI [CN]) 28 April 2004 (2004-04-28) paragraph [0024]; figures 2-6	1-12
A	US 2008/049126 A1 (FORD LORISTON [US] ET AL) 28 February 2008 (2008-02-28) figures 1-10B	1-12
A	EP 2 239 777 A2 (FUJIFILM CORP [JP]) 13 October 2010 (2010-10-13) figures 1-2,9	1-12

☐ 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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 November 2018	16/11/2018

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

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/073541

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009250594 A1	08-10-2009	JP 2009252978 A	29-10-2009
		US 2009250594 A1	08-10-2009
US 2009166518 A1	02-07-2009	BR PI0822173 A2	16-06-2015
		CN 101971339 A	09-02-2011
		DE 112008003468 T5	20-01-2011
		ES 2422869 A1	16-09-2013
		ES 2545429 A2	10-09-2015
		GB 2469247 A	06-10-2010
		GB 2485715 A	23-05-2012
		GB 2487010 A	04-07-2012
		GB 2487013 A	04-07-2012
		GB 2487014 A	04-07-2012
		GB 2488468 A	29-08-2012
		GB 2488470 A	29-08-2012
		HK 1171566 A1	22-11-2013
		HK 1171568 A1	22-11-2013
		HK 1175303 A1	22-11-2013
		HK 1175304 A1	22-11-2013
		JP 6079978 B2	20-09-2017
		JP 2011508457 A	10-03-2011
		SG 187382 A1	28-02-2013
		TW 200947684 A	16-11-2009
		TW 201415616 A	16-04-2014
		TW 201543661 A	16-11-2015
		US 2009166518 A1	02-07-2009
		US 2010155870 A1	24-06-2010
		US 2010283112 A1	11-11-2010
		US 2011027936 A1	03-02-2011
		US 2013034927 A1	07-02-2013
		US 2014117208 A1	01-05-2014
		WO 2009091484 A1	23-07-2009
EP 1414073 A2	28-04-2004	CN 1531100 A	22-09-2004
		EP 1414073 A2	28-04-2004
		TW I240992 B	01-10-2005
		US 2004080008 A1	29-04-2004
		US 2005098842 A1	12-05-2005
US 2008049126 A1	28-02-2008	US 2008049126 A1	28-02-2008
		US 2014061836 A1	06-03-2014
		US 2017338266 A1	23-11-2017
		US 2018301493 A1	18-10-2018
EP 2239777 A2	13-10-2010	CN 101848345 A	29-09-2010
		EP 2239777 A2	13-10-2010
		JP 4741015 B2	03-08-2011
		JP 2010232537 A	14-10-2010
		KR 20100108263 A	06-10-2010
		TW 201104854 A	01-02-2011
		US 2010245638 A1	30-09-2010
		US 2014139708 A1	22-05-2014