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(54) **THERMALLY TUNABLE OPTOELECTRONIC MODULES**

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G02B 1/02	(2006.01)
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H01S 5/022	(2006.01)

(Continued)

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(58) **Field of Classification Search**
CPC G02B 7/028; G02B 19/0014; G02B 19/0057; G02B 1/02; G02B 26/007; G02B 19/0009; G02B 7/008; H01S 5/18386; H01S 5/0228; H01S 5/423; H01S 5/02296; H01S 5/02469; H01S 5/183; H01S 5/02244; G06T 7/521
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,410,563 A * 4/1995 Nakamura B41J 2/471 372/101
9,273,846 B1 3/2016 Rossi et al.
(Continued)

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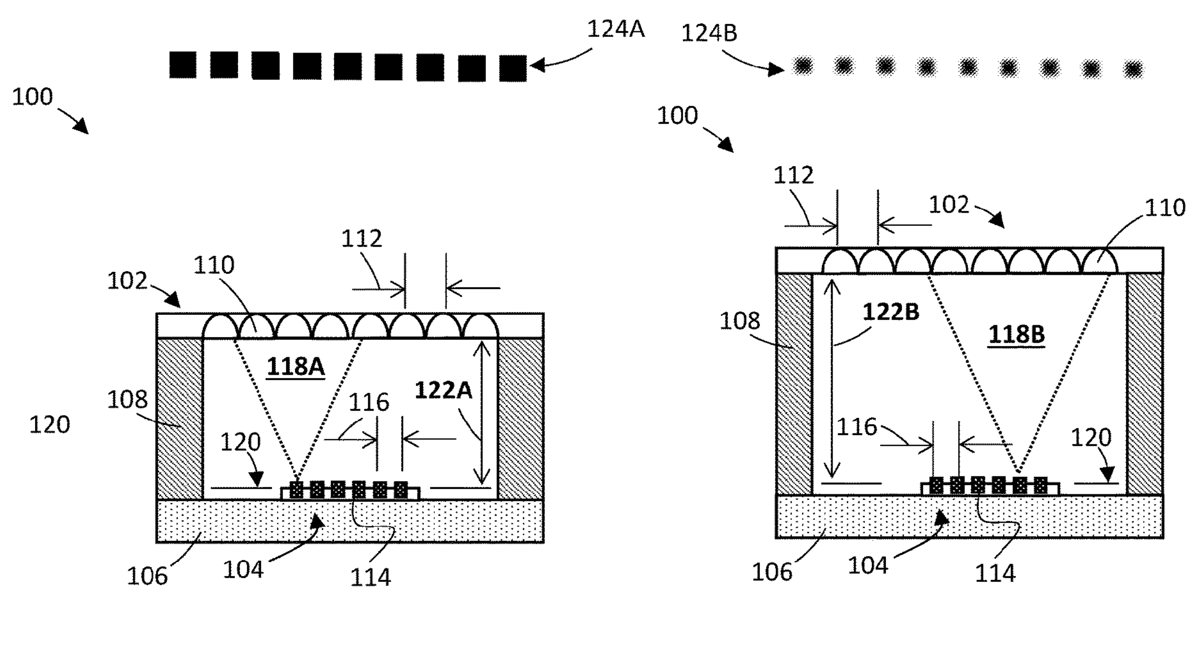
(57) **ABSTRACT**

A thermally tunable optoelectronic module includes a light emitting assembly operable to emit light of a particular wavelength or range of wavelengths. The light emitting assembly is disposed to a temperature-dependent wavelength shift. The thermally tunable optoelectronic module further includes an optical assembly aligned to the light emitting assembly, and separated from the light emitting assembly by an alignment distance. The thermally tunable optoelectronic module further includes a thermally tunable spacer disposed between the optical assembly and the light-emitting assembly, the thermally tunable spacer is operable to counteract the temperature-dependent wavelength shift.

14 Claims, 2 Drawing Sheets



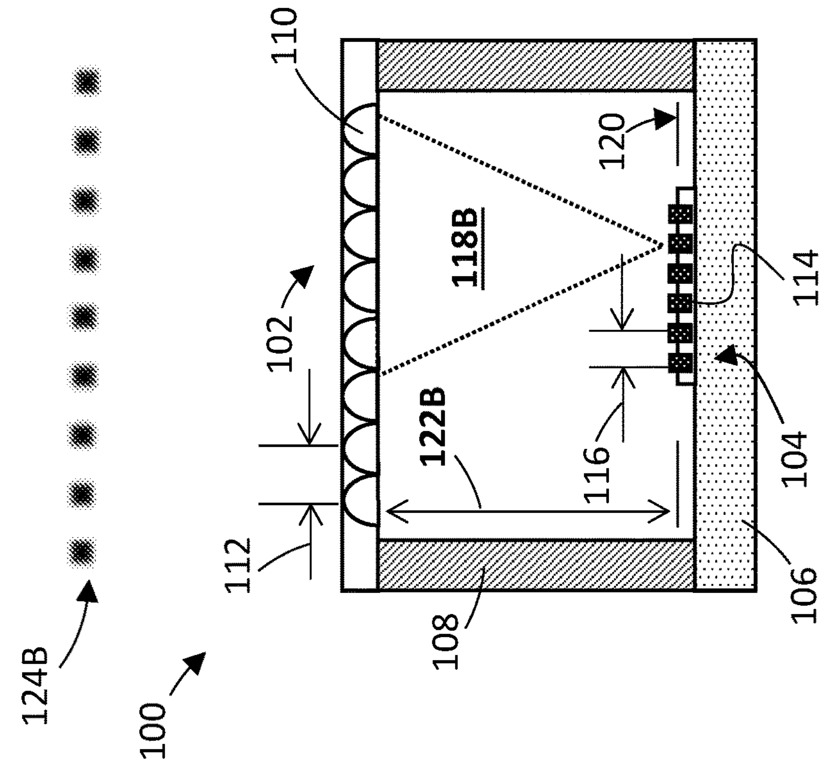
(51) **Int. Cl.**
H01S 5/024 (2006.01)
H01S 5/42 (2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

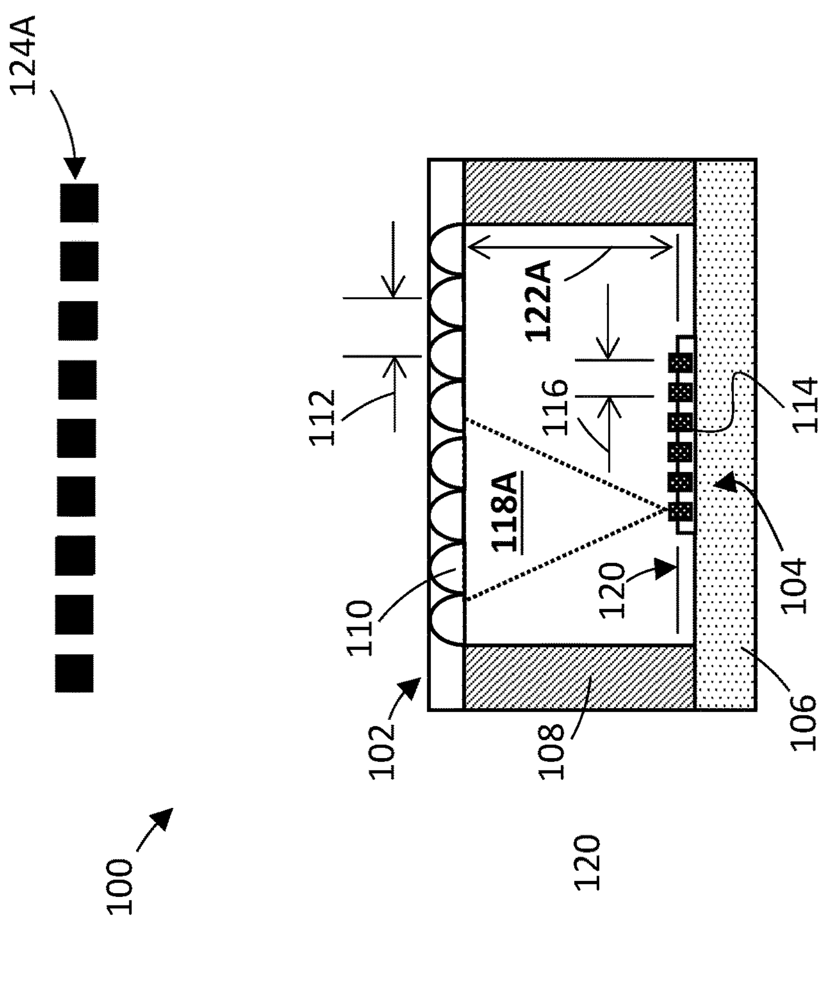
2004/0070833	A1*	4/2004	Sargent	G02B 5/281	359/577
2010/0171813	A1*	7/2010	Pelman	G01S 17/89	348/46
2013/0038941	A1*	2/2013	Pesach	G01B 11/25	359/619
2014/0192424	A1*	7/2014	Matsui	G02B 13/003	359/717
2014/0376092	A1*	12/2014	Mor	G01B 11/2513	359/569
2015/0355470	A1*	12/2015	Herschbach	G02B 27/0977	362/11

* cited by examiner



110
120
118B
102
114
122B
116
104
112
108
106
124B
100

FIG. 1B



124A
122A
112
116
114
118A
120
104
110
102
108
106
100
120

FIG. 1A

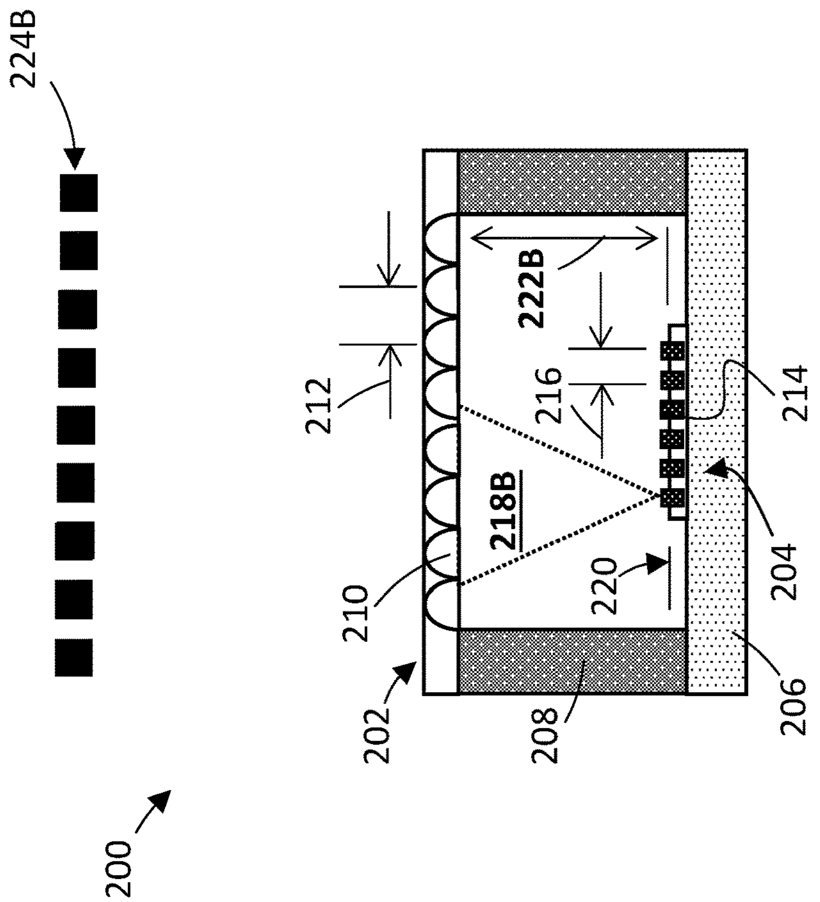

224B
212
222B
216
214
210
218B
220
204
202
208
206
200

FIG. 2B

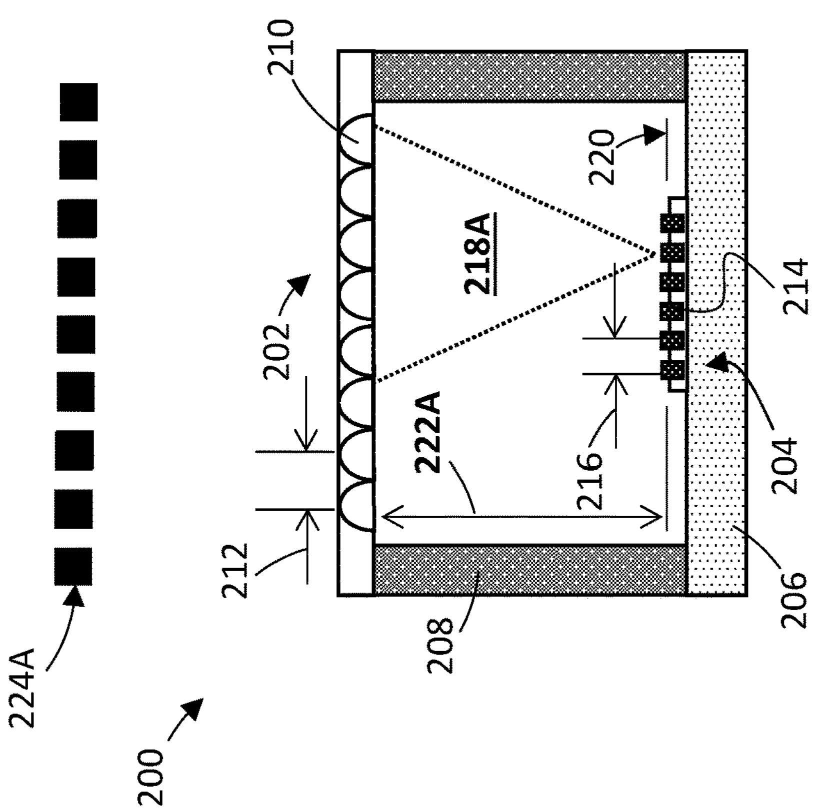

210
220
218A
214
202
222A
216
204
212
208
206
224A
200

FIG. 2A

THERMALLY TUNABLE OPTOELECTRONIC MODULES

FIELD OF THE DISCLOSURE

The present disclosure relates to thermally tunable optoelectronic modules.

BACKGROUND

An example of a typical light-emitting optoelectronic module may include a light-emitting assembly aligned with an optical assembly or series of optical assemblies. The light-emitting element may include a high-power laser diode or an array of high-power laser diodes operable to generate light of a particular wavelength or wavelengths. The optical assembly may include a refractive or diffractive lens, arrays or series of refractive and/or diffractive lenses, a microlens array or a series of microlens arrays operable to direct light of the particular wavelength or range of wavelengths. Together the light-emitting assembly and the optical assembly may be operable to generate (e.g., project) a light pattern of high-contrast features over a range of operating temperatures. During normal operation, the module's operating temperature may fluctuate, thereby causing the optical assembly and light-emitting assembly to become misaligned. Temperature fluctuations also may alter characteristics of the light-emitting assembly, such as the wavelength of light it generates. Both effects may strongly degrade optical performance during typical operation, therefore limiting the effectiveness or potential applications of such light-emitting optoelectronic modules to narrow operating temperatures.

For instance, a light-emitting optoelectronic module that includes a refractive lens with a focal length, and a vertical-cavity surface-emitting laser (VCSEL) array with an emission plane may be susceptible to such degradation in optical performance during typical operation. In this instance, the refractive lens should be aligned to the VCSEL array when the focal length is incident on the emission plane. Hence, the refractive lens and the VCSEL array can be aligned and mounted to a spacer. The spacer may be composed of a material having a positive thermal expansion coefficient. Typically, during operation, the VCSEL array generates a sufficiently high level of heat so to cause the spacer to expand. The expansion can cause the refractive lens and VCSEL array to become misaligned (i.e., the focal length of the refractive lens is no longer incident on the emission plane of the VCSEL array) at some operating temperatures. In some instances, this misalignment significantly degrades the optical performance of the light-emitting optoelectronic module at some operating temperatures.

In another instance, a light-emitting optoelectronic module includes a diffractive lens, such as a Fresnel-like diffractive lens or other diffractive optical assembly, and a VCSEL array arranged to emit a particular wavelength. The diffractive lens is specifically designed for the specific wavelength emitted by the VCSEL array. However, during operation, the VCSEL array generates sufficiently high level of heat so to shift the light emitted by the VCSEL array to longer wavelengths (e.g., 0.3 nm K^{-1}). In some cases, such VCSEL arrays heat up to 80 K or even 100 K above the temperature for which the light-emitting optoelectronic module specifically was designed, thereby causing significant shifts to longer wavelengths and a concurrent degradation in optical performance of the light-emitting optoelectronic module.

In some instances, a light-emitting optoelectronic module includes a microlens array and a VCSEL array. The optical performance of such light-emitting optoelectronic modules is strongly dependent on the alignment of the microlens array and the VCSEL array, as well as the wavelength of light emitted by the VCSEL array. However, as described above, significant fluctuations in operating temperature can cause the microlens array and the VCSEL array to become misaligned due to fluctuations in material dimensions, and further can cause a shift in wavelengths emitted by the VCSEL array.

SUMMARY

The present disclosure describes thermally tunable optoelectronic modules that, in some cases, are capable of mitigating or completely negating optical performance degradation due to fluctuations in operating temperature.

For example, in one aspect, a thermally tunable optoelectronic module includes a light emitting assembly. The light emitting assembly is operable to emit light of a particular wavelength or range of wavelengths. The light emitting assembly is disposed to a temperature-dependent wavelength shift. The thermally tunable optoelectronic module further includes an optical assembly aligned to the light emitting assembly. The optical assembly is separated from the light emitting assembly by an alignment distance. The thermally tunable optoelectronic module further includes a thermally tunable spacer disposed between the optical assembly and the light-emitting assembly. The thermally tunable spacer is operable to counteract the temperature-dependent wavelength shift.

Some implementations include one or more of the following features. For example, the thermally tunable optoelectronic module can include an optical assembly with an array of microlenses. The microlenses can be disposed with respect to each other by a microlens array pitch. The light-emitting assembly can include an array of light-emitting elements, where the light-emitting elements are disposed with respect to each other by a light-emitting element array pitch.

In some instances, the thermally tunable optoelectronic module includes an alignment distance substantially equal to a non-zero whole number integer divided by two. The dividend is multiplied by the square of the microlens array pitch divided by the particular wavelength or range of wavelengths emitted by the light emitting assembly.

In some cases, the thermally tunable optoelectronic module includes an alignment distance substantially equal to a non-zero whole number integer divided by two. The dividend is multiplied by the square of the light-emitting element array pitch divided by the particular wavelength or range of wavelengths emitted by the light emitting assembly.

In some implementations, the thermally tunable optoelectronic module includes a light emitting element that includes a laser diode.

In some instances, the thermally tunable optoelectronic module includes a thermally tunable spacer that exhibits negative thermal expansion along the alignment distance.

In some case, the thermally tunable optoelectronic module includes a light-emitting element that generates a particular wavelength or range of wavelengths that correspond to the infrared portion of the electromagnetic spectrum.

In some implementations, the thermally tunable optoelectronic module includes a laser diode that is a vertical-cavity surface-emitting laser.

In some cases, the thermally tunable optoelectronic module includes a heat sink.

In some instances, the thermally tunable optoelectronic module includes a lead frame.

In some implementations, the thermally tunable optoelectronic module includes a light-emitting assembly mounted to a printed circuit board.

In some cases, the thermally tunable optoelectronic module includes a thermally tunable spacer at least partially composed of a material having a negative thermal expansion coefficient.

In some instances, the thermally tunable optoelectronic module includes a liquid crystal polymer.

In another example aspect a thermally tunable optoelectronic module includes a liquid crystal polymer with an orientation direction and a cross flow direction. The cross flow direction is substantially aligned with an alignment distance.

In some implementations, the thermally tunable optoelectronic module includes an inorganic oxide material with a negative thermal expansion coefficient.

In some instances, the thermally tunable optoelectronic module includes at least one of: ZrW_2O_8, HfW_2O_8, $ZrMo_2O_8$, $HfMo_2O_8$, $ZrV_2O_7.Zr_2(MoO_4)_3$, $ZrV_2O_7.Hf_2(MoO_4)_3$, $ZrV_2O_7.Zr_2(WO_4)_3$, $ZrV_2O_7.Hf_2(WO_4)_3$, or $CuScO_2$.

Other aspects, features and advantages will be readily apparent from the following detailed description, the accompanying drawing and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A depicts an example light-emitting optoelectronic module operating at a first operating temperature.

FIG. **1**B depicts the example light-emitting optoelectronic module depicted in FIG. **1**A operating at a second operating temperature.

FIG. **2**A depicts an example thermally tunable light-emitting optoelectronic module operating at a first operating temperature.

FIG. **2**B depicts the example thermally tunable light-emitting optoelectronic module depicted in FIG. **2**A operating at a second operating temperature.

DETAILED DESCRIPTION

FIG. **1**A depicts a light-emitting optoelectronic module **100** such as the light-emitting optoelectronic modules disclosed in U.S. Pat. No. 9,273,846 B1, which is incorporated herein by reference in its entirety. FIG. **1**A depicts the light-emitting optoelectronic module **100** operating at a first operating temperature. The light-emitting optoelectronic module **100** includes an optical assembly **102**, a light-emitting assembly **104**, a substrate **106**, and a spacer **108**. In this example, the optical assembly **102** is a microlens array including an array of microlenses **110** disposed with respect to each other by a microlens array pitch **112**. The microlens array pitch **112** can be in the range, e.g., of 20 μm to 100 μm, for example 50 μm. Other pitches can be used in some implementations. In the illustrated example, the light-emitting assembly **104** is an array of light-emitting elements **114** (e.g., VCSEL array including an array of VCSEL diodes) disposed with respect to each other by a light-emitting element array pitch **116**. The light-emitting element array pitch **116** can be in the range, e.g., of 20 μm to 100 μm, for example 50 μm. Other pitches can be used in some implementations. The light-emitting assembly **104** is operable to emit light **118**A of a particular wavelength from a common emission plane **120**. The light-emitting assembly **104** can emit light **118**A of any wavelength; for example, 850 nm or 940 nm. The optical assembly **102** is aligned with the emission plane **120**; that is, the optical assembly **102** is separated from the emission plane **120** by an alignment distance **122**A. The alignment distance **122**A can be in the range, e.g., of 1.5 mm to 6 mm, for example 2.94 mm. The light-emitting assembly **104** is mounted (e.g., electrically and/or mechanically mounted) to the substrate **106**. The substrate **106** can be a printed circuit board, for example. The optical assembly **102** is separated from the light-emitting assembly **104** by the spacer **108** thereby establishing the alignment distance **122**A between the optical assembly **102** and the emission plane **120**. The spacer **108** can be composed of a polymeric material such as an epoxy resin. Light **118**A emitted from the light-emitting assembly **104** is incident on the optical assembly **102**, wherein a pattern **124**A of high contrast features is produced in the far field at a first operating temperature.

In some instances, the microlens array pitch **112** and the light-emitting element array pitch **116** are different from one another. In other instances, the microlens array pitch **112** and the light-emitting element array pitch **116** are substantially equal, as depicted in FIG. **1**A, wherein the microlens array pitch **112**, the light-emitting element array pitch **116**, the particular wavelength of the light **118**A is selected and the alignment distance **122**A is arranged according to the following, Eq. 1:

$$Z=(P)^2/\lambda \quad \text{Eq. 1}$$

where the microlens array pitch **112** and the light-emitting element array pitch **116** are equal and are represented by P, the particular wavelength of light **118**A is represented by λ, and the alignment distance **122**A is represented by Z. For example, when the microlens array pitch **112** is 50 μm, the light-emitting element array pitch **116** is 50 μm, and the light-emitting assembly **104** emits light **118**A of 850 nm, the alignment distance **122**A is 2.94 mm. As disclosed in U.S. Pat. No. 9,273,846 B1, such an arrangement of microlens array pitch **112**, light-emitting element array pitch **116**, wavelength of light **118**A, and alignment distance **122**A can produce the pattern **124**A of particularly high-contrast features is the far field at the first operating temperature.

FIG. **1**B depicts the example light-emitting optoelectronic module **100** illustrated in FIG. **1**A operating at a second operating temperature greater than the first operating temperature. In this example, both the light **118**A and the alignment distance **122**A are affected by the change in temperature. The light **118**A produced by the light emitting element shifts to longer wavelengths. In some instances, the wavelength increases by 0.3 nm K^{-1} increase in temperature. For example, for a 100 K increase in temperature, a 30.0 nm increase in wavelength can occur.

However, in order to satisfy the relationship given in Eq. 1 at the longer wavelengths and maintain optical performance, the alignment distance **122**A and/or the pitches **112**, **116** must be modified. Thus, an increase in wavelength would necessitate a contraction in the alignment distance **122**A to maintain the same optical performance. For example, given a light-emitting optoelectronic module **100** with a microlens array pitch **112** of 50 μm, a light-emitting element array pitch **116** of 50 μm, light **118**A of 850 nm, and an alignment distance **122**A of 2.94 mm, an increase in wavelength of 30.0 nm would require a contraction of the alignment distance **122**A of 100 μm to yield a pattern **124**A with the same high-contrast features. Generally, for such optoelectronic modules designed for the first operating temperature, the contrast of the pattern **124**A will be lower at the second operating temperature as depicted by pattern **124**B in FIG. **1**B.

Moreover, as the spacer **108** is composed of a material having a positive thermal expansion coefficient, the alignment distance **122** B will be larger at the second operating temperature as depicted by alignment distance **122**B in FIG. **1**B. If, for example, the spacer **108** is composed of cast epoxy resin with a linear thermal expansion coefficient of 45×10^{-6} K^{-1}, an increase in operating temperature of 100 K, and a spacer **108** length equal to the alignment distance **122**A of 2.94 mm, the spacer **108** may increase in length as much as 13.2 μm. Such an increase may severely degrade optical performance of the light-emitting optoelectronic module **200**.

FIG. **2**A depicts a thermally tunable light-emitting optoelectronic module **200** operating at a first operating temperature. The thermally tunable light-emitting optoelectronic module **200** includes an optical assembly **202**, a light-emitting assembly **204**, and a substrate **206** as disclosed for the example optoelectronic module **100** depicted in FIGS. **1**A and **1**B. The light-emitting optoelectronic module **200** depicted in FIG. **2**A further includes a thermally tunable spacer **208** composed (at least in part) of a negative thermal expansion material; for example, a liquid crystal polymer, ZrW_2O_8, $Sc(WO_4)_3$, HfW_2O_8, $ZrMo_2O_8$, $HfMo_2O_8$, $ZrV_2O_7.Zr_2(MoO_4)_3$, $ZrV_2O_7.Hf_2(MoO_4)_3$, $ZrV_2O_7.Zr_2(WO_4)_3$, $ZrV_2O_7.Hf_2(WO_4)_3$, or $CuScO_2$. In some instances, the linear coefficient of thermal expansion of such materials can range from $-9.1\ 10^{-6}$ K^{-1} for ZrW_2O_8 to $-2.2\ 10^{-6}$ K^{-1} for $Sc(WO_4)_3$ (as reported by J. S. O. Evans in the Journal of the Chemical Society Dalton Transactions, 1999, 3317).

The light-emitting optoelectronic module **200** further includes an array of microlenses **210** disposed with respect to each other at a microlens array pitch **212**. In this example, the light-emitting assembly **204** is a VCSEL array that includes an array of VCSEL diodes **214** disposed with respect to each other at a light-emitting element array pitch **216**. The light-emitting assembly **204** is operable to emit light **218**A of a particular wavelength from a common emission plane **220**. The optical assembly **202** is aligned with the emission plane **220**; that is, the optical assembly **202** is separated from the emission plane **220** by an alignment distance **222**A. The light-emitting assembly **204** is mounted (e.g., electrically and/or mechanically mounted) to the substrate **206**. The substrate **206** is a printed circuit board in this example. The optical assembly **202** can be disposed from the light-emitting assembly **204** by the thermally tunable spacer **208** thereby establishing the alignment distance **222**A between the optical assembly **202** and the emission plane **220**. Light **218**A emitted from the light-emitting assembly **204** is incident on the optical assembly **202**, wherein a pattern **224**A of high contrast features is produced in the far field at a first operating temperature.

In some instances, the microlens array pitch **212** and the light-emitting element array pitch **216** are different from one another. In other instances, the microlens array pitch **212** and the light-emitting element array pitch **216** are substantially equal, as depicted in FIG. **2**A, wherein the microlens array pitch **212**, the light-emitting element array pitch **216**, the particular wavelength of the light **218**A, and the alignment distance **222**A are arranged according to Eq. 1. In this example, the microlens array pitch **212** and the light-emitting element array pitch **216** are equal and, therefore, are both represented by P, the particular wavelength of light **218**A is represented by λ, and the alignment distance **222**A is represented by Z. As disclosed above, such an arrangement of microlens array pitch **212**, light-emitting element array pitch **216**, wavelength of light **218**A, and alignment distance **222**A produces the pattern **224**A of particularly high-contrast features in the far field at the first operating temperature.

FIG. **2**B depicts the example light-emitting optoelectronic module **200** illustrated in FIG. **2**A operating at a second operating temperature greater than the first operating temperature. The light **218**A and the alignment distance **222**A are affected by the change in temperature. The light **218**A produced by the light emitting element shifts to longer wavelengths **218**B as described above deviating from the relationship described by Eq. 1. However, as the thermally tunable spacer **208** is composed at least in part of a negative thermal expansion material, the alignment distance **222**B is smaller (rather than larger as in FIG. **1**B) at the second, in this case, higher operating temperature. Accordingly, the aforementioned shift to longer wavelengths is counteracted, at least in part, by the smaller alignment distance **222**B as the wavelength **218**B and the alignment distance **222**B together substantially satisfy the relationship described by Eq. 1. Consequently, the optical performance of the thermally tunable light-emitting optoelectronic module **200** will not significantly degrade, i.e., the pattern **224**B will have similar contrast as the pattern **224**A depicted in FIG. **2**A.

In some implementations, the thermally tunable spacer **208** is formed from a composite composed of a particular ratio of constituent materials, where the composite is formulated to counteract the wavelength shift described above. For example, the thermally tunable spacer **208** can be formed from a composite composed of two materials each with a different thermal expansion coefficient. The proportion of the two materials within the composite can be determined by a simple rule of mixtures such that the net thermal expansion coefficient of the composite is substantially similar to the wavelength shift described above.

For example, in some cases, the thermally tunable light-emitting optoelectronic module **200** described above is arranged according to Eq. 1, where: P=50 μm, λ=~850 nm, Z=2.94 mm, and wavelength shift=0.3 nm K^{-1}. Further, according to Eq. 1, a 100 K increase would cause a deviation of Z in Eq. 1 by 100 μm. Consequently, the thermally tunable spacer **208** contracts by 100 μm in order to maintain the same optical performance, which can be expressed as a target coefficient of thermal expansion: $(\Delta T)\times(\Delta Z)/Z=340\times10^{-6}$ K^{-1} in this example. A composite composed of ZrW_2O_8 and cast epoxy resin with thermal expansion coefficients of -9.1×10^{-6} K^{-1} and 45×10^{-6} K^{-1}, respectively, could be formulated according to the following: $(-9.1\times10^{-6}\ K^{-1})(X)+(45\times10^{-6}\ K^{-1})(Y)=340\times10^{-6}\ K^{1}$ where X and Y are the fraction ZrW_2O_8 of and the cast epoxy resin, respectively.

Further, although the alignment distance **222**A, **222**B, the wavelength of the emitted light **218**A, **218**B, the microlens array pitch **212**, and the light-emitting element array pitch **216** are arranged according to Eq. 1. Other arrangements are within the scope of this disclosure. For example, the alignment distance **222**A, **222**B, the wavelength of the emitted light **218**A, **218**B, the microlens array pitch **212**, and the light-emitting element array pitch **216** is arranged according to Eq. 2 where:

$$Z=(n/2)(P)^2/\lambda \qquad \text{Eq. 2}$$

where n is a non-zero whole integer, the microlens array pitch **212** and the light-emitting element array pitch **216** are equal and are represented by P, the particular wavelength of light **218**A, **218**B is represented by λ, and the alignment distance **222**A, **222**B is represented by Z. As disclosed in U.S. Pat. No. 9,273,846 B1, such an arrangement of microlens array pitch **212**, light-emitting element array pitch **216**, wavelength of light **218**A, **218**B and alignment distance **222**A, **224**B can produce the pattern **224**A, **224**B of particularly high-contrast features is the far field at a range of operating temperatures.

The foregoing description describes example implementations. Various modifications, however, can be made within the spirit of the disclosure. Accordingly, other implementations are within the scope of the claims.

What is claimed is:

1. A thermally tunable optoelectronic module comprising:

a light emitting assembly operable to emit light of a particular wavelength or range of wavelengths, the light emitting assembly being disposed to a temperature-dependent wavelength shift;

an optical assembly aligned to the light emitting assembly, the optical assembly being separated from the light emitting assembly by an alignment distance; and

a thermally tunable spacer disposed between the optical assembly and the light-emitting assembly, the thermally tunable spacer being operable to counteract the temperature-dependent wavelength shift, wherein the thermally tunable spacer exhibits negative thermal expansion along the alignment distance.

2. The optoelectronic module of claim **1**, wherein the optical assembly includes an array of microlenses disposed with respect to each other at a microlens array pitch, and wherein the light-emitting assembly includes an array of light-emitting elements disposed with respect to each other at a light-emitting element array pitch.

3. The optoelectronic module of claim **2**, wherein the alignment distance is substantially equal to a non-zero whole number integer divided by two, the dividend being multiplied by the square of the microlens array pitch divided by the particular wavelength or range of wavelengths emitted by the light emitting assembly.

4. The optoelectronic module of claim **2**, wherein the alignment distance is substantially equal to a non-zero whole number integer divided by two, the dividend being multiplied by the square of the light-emitting element array pitch divided by the particular wavelength or range of wavelengths emitted by the light emitting assembly.

5. The optoelectronic module as in claim **1**, in which the light emitting element includes a laser diode.

6. The optoelectronic module of claim **5**, wherein the laser diode is a vertical-cavity surface-emitting laser.

7. The optoelectronic module as in claim **1**, in which the particular wavelength or range of wavelengths corresponds to the infrared portion of the electromagnetic spectrum.

8. The optoelectronic module as in claim **1**, in which the optoelectronic module further includes a heat sink.

9. The optoelectronic module as in claim **1**, in which the optoelectronic module further includes a lead frame.

10. The optoelectronic module of claim **1**, in which the light-emitting assembly is mounted to a printed circuit board.

11. A thermally tunable optoelectronic module comprising:

a light emitting assembly operable to emit light of a particular wavelength or range of wavelengths, the light emitting assembly being disposed to a temperature-dependent wavelength shift;

an optical assembly aligned to the light emitting assembly, the optical assembly being separated from the light emitting assembly by an alignment distance; and

a thermally tunable spacer disposed between the optical assembly and the light-emitting assembly, the thermally tunable spacer being operable to counteract the temperature-dependent wavelength shift in which the thermally tunable spacer is at least partially composed of a material having a negative thermal expansion coefficient;

wherein the material having a negative thermal expansion coefficient is a liquid crystal polymer.

12. The optoelectronic module as in claim **11**, the liquid crystal polymer being characterized by an orientation direction and a cross flow direction, the cross flow direction being substantially aligned with the alignment distance.

13. A thermally tunable optoelectronic module comprising:

a light emitting assembly operable to emit light of a particular wavelength or range of wavelengths, the light emitting assembly being disposed to a temperature-dependent wavelength shift;

an optical assembly aligned to the light emitting assembly, the optical assembly being separated from the light emitting assembly by an alignment distance; and

a thermally tunable spacer disposed between the optical assembly and the light-emitting assembly, the thermally tunable spacer being operable to counteract the temperature-dependent wavelength shift in which the thermally tunable spacer is at least partially composed of a material having a negative thermal expansion coefficient;

wherein the material having a negative thermal expansion coefficient is an inorganic oxide material.

14. The optoelectronic module as in claim **13**, wherein the inorganic oxide is at least partially composed of ZrW_2O_8, HfW_2O_8, $ZrMo_2O_8$, $HfMo_2O_8$, $ZrV_2O_7.Zr_2(MoO_4)_3$, $ZrV_2O_7.Hf_2(MoO_4)_3$, $ZrV_2O_7.Zr_2(WO_4)_3$, $ZrV_2O_7.Hf_2(WO_4)_3$, or $CuScO_2$.

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