Claims

1. A lens manufacturing method, comprising:

coating photoresists varying in refractive index on a lens substrate; and

inducing, by a laser beam emitted from a laser system, a photopolymerization reaction of the photoresists to lithographically form at least two micro/nano structure sets varying in optical properties on the lens substrate, thereby obtaining a lens having the at least two micro/nano structure sets arranged in a predetermined layout, wherein the lens realizes a required refractive-index distribution through the at least two micro/nano structure sets in the predetermined layout, and a minimum feature size of the at least two micro/nano structure sets is 50 nanometers;

characterized in that each of the at least two micro/nano structure sets comprises a micropillar array and gradient microlenses; in a far-vision region of the lens, a micropillar array having fixed height and diameter is designed, and by adjusting a material refractive index and an arrangement density of the micropillar array, a stable dioptric power required in the far-vision region is achieved; and in a transition region and a near-vision region, the gradient microlenses are arranged, with a radius of curvature of the gradient microlenses decreasing from the far-vision region to the near-vision region to achieve a smooth transition of dioptric power, and by adjusting a height and curvature of the gradient microlenses, a refraction angle of light is controlled to satisfy vision correction needs at different distances;

wherein distribution of each of the at least two micro/nano structure sets comprises axial distribution and radial distribution;

in the axial distribution: "axial" refers to a direction from a top of the lens to a bottom of the lens; in the far-vision region, the at least two micro/nano structure sets remain uniformly distributed; upon entering the transition region, sizes and arrangement densities of the at least two micro/nano structure sets vary according to a linear gradient function or an S-shaped gradient function to ensure a smooth transition of dioptric power; and in the near-vision region, a final distribution state of each of the at least two micro/nano structure sets is determined according to near-vision correction needs;

in the radial distribution: "radial" refers to a horizontal direction with a lens center as a

center; in a central region of the lens, each of the at least two micro/nano structure sets is distributed relatively densely and uniformly to ensure central vision clarity; toward an edge region, the distribution gradually becomes sparser, and shapes and sizes of the at least two micro/nano structure sets are adjusted to compensate for aberrations caused by edge refraction; and

a defocus amount De of each of the at least two micro/nano structure sets satisfies: +4.00 D ≤ De ≤ +10.00 D, wherein D represents diopters, and +10.00 D is an extreme defocus; each of the gradient microlenses reaches the extreme defocus within a field angle of 8°; the defocus amount of each of the at least two micro/nano structure sets is positively correlated with the field angle, such that the defocus amount increases as the field angle increases, and an effective defocus amount in a micro/nano-structure region is larger.

2. The lens manufacturing method according to claim 1, characterized in that the photoresists each have a two-photon absorption characteristic, and the lithography is two-photon lithography; a refractive index of each of the photoresists is between 1.5 and 1.9; a coating thickness of each of the photoresists is greater than or equal to 100 nm; and the photoresists are each coated by spin coating, drop coating, or spray coating.

3. The lens manufacturing method according to claim 1, further comprising:

before coating the photoresists, pre-treating a surface of the lens substrate, wherein the pre-treatment comprises cleaning, degreasing, or surface activation;

after coating the photoresists, pre-curing the coated photoresists, wherein the pre-curing comprises thermal treatment to volatilize the photoresists, and an amount of volatilization is less than or equal to 40%; and

after lithography, post-treating a surface of the lens substrate, wherein the post-treatment comprises removing remaining photoresists on the lens substrate, adding an anti-reflection coating, adding a hydrophobic coating, or performing optical-performance inspection.

4. A progressive lens, comprising:

a lens substrate; and

at least two micro/nano structure sets varying in optical properties, which are formed on the lens substrate through photopolymerization;

characterized in that a required refractive-index distribution is realized through the at least two micro/nano structure sets arranged in a predetermined layout;

a minimum feature size of the at least two micro/nano structure sets is 50 nanometers;

the at least two micro/nano structure sets are formed on the lens substrate by coating photoresists varying in refractive index and photopolymerization;

wherein each of the at least two micro/nano structure sets comprises a micropillar array and gradient microlenses; in a far-vision region of the lens, the micropillar array having substantially fixed height and diameter is designed, and by adjusting a material refractive index and an arrangement density of the micropillar array, a relatively stable dioptric power required in the far-vision region is achieved; and in a transition region and a near-vision region, the gradient microlenses are arranged, with a radius of curvature of the gradient microlenses gradually decreasing from the far-vision region to the near-vision region to achieve a smooth transition of dioptric power, and by adjusting a height and curvature of the gradient microlenses, a refraction angle of light is controlled to satisfy vision correction needs at different distances;

wherein distribution of each of the at least two micro/nano structure sets comprises axial distribution and radial distribution;

in the axial distribution: "axial" refers to a direction from a top of the lens to a bottom of the lens; in the far-vision region, the at least two micro/nano structure sets remain uniformly distributed; upon entering the transition region, sizes and arrangement densities of the at least two micro/nano structure sets vary according to a linear gradient function or an S-shaped gradient function to ensure a smooth transition of dioptric power; and in the near-vision region, a final distribution state of each of the at least two micro/nano structure sets is determined according to near-vision correction needs;

in the radial distribution: "radial" refers to a horizontal direction with a lens center as a center; in a central region of the lens, the at least two micro/nano structure sets are distributed relatively densely and uniformly to ensure central vision clarity; toward an edge region, the distribution gradually becomes sparser, and shapes and sizes of the at least two micro/nano structure sets are slightly adjusted to compensate for aberrations caused by edge refraction;

wherein a defocus amount De of each of the at least two micro/nano structure sets satisfies: +4.00 D ≤ De ≤ +10.00 D, wherein D represents diopters and +10.00 D is an extreme defocus; each of the gradient microlenses reaches the extreme defocus within a field angle of 8°; the defocus amount of each of the at least two micro/nano structure sets is positively correlated with the field angle, such that the defocus amount increases as the field angle increases, and an effective defocus amount in a micro/nano-structure region is larger.

5. The progressive lens according to claim 4, characterized in that each of the at least two micro/nano structure sets comprises optical waveguides or optical antennas; the at least two micro/nano structure sets are designed to modulate a polarization state of light passing through the lens substrate to provide a polarization modulation function; or

the at least two micro/nano structure sets are designed to realize a temperature-responsive function of the lens substrate by changing a state of a temperature-sensitive material in the lens substrate to adjust optical performance of the lens substrate.

6. The progressive lens according to claim 4, characterized in that a surface of the progressive lens has a scratch-resistant coating, an ultraviolet-blocking coating, a blue-light filtering coating, a superhydrophobic coating, or a superoleophobic coating.

7. A lens manufacturing system, comprising:

a femtosecond laser;

a focusing optical system;

a three-dimensional motion stage;

a photoresist feeding device; and

a software for designing and simulating micro/nano structures;

characterized in that the three-dimensional motion stage is configured to load and move a lens substrate and to drive the lens substrate to rotate;

the photoresist feeding device is configured to coat photoresists varying in refractive index on the lens substrate;

the femtosecond laser is configured, according to a micro/nano-structure pattern provided

by the software, to perform lithography on the lens substrate after the photoresists are coated, so as to obtain at least two micro/nano structure sets varying in optical properties on the lens substrate, thereby realizing a required refractive-index distribution through the micro/nano structures;

the focusing optical system is configured to control scanning speed and focal length of a laser beam emitted by the femtosecond laser;

a minimum feature size of the at least two micro/nano structure sets is 50 nanometers;

wherein each of the at least two micro/nano structure sets comprises a micropillar array and gradient microlenses; in a far-vision region of the lens, the micropillar array having substantially fixed height and diameter is designed, and by adjusting a material refractive index and an arrangement density of the micropillar array, a relatively stable dioptric power required in the far-vision region is achieved; and in a transition region and a near-vision region, the gradient microlenses are arranged, with a radius of curvature of the gradient microlenses gradually decreasing from the far-vision region to the near-vision region to achieve a smooth transition of dioptric power, and by adjusting a height and curvature of the gradient microlenses, a refraction angle of light is controlled to satisfy vision correction needs at different distances;

wherein distribution of each of the at least two micro/nano structure sets comprises axial distribution and radial distribution;

in the axial distribution: "axial" refers to a direction from a top of the lens to a bottom of the lens; in the far-vision region, the at least two micro/nano structure sets remain uniformly distributed; upon entering the transition region, sizes and arrangement densities of the at least two micro/nano structure sets vary according to a linear gradient function or an S-shaped gradient function to ensure a smooth transition of dioptric power; and in the near-vision region, a final distribution state of each of the at least two micro/nano structure sets is determined according to near-vision correction needs;

in the radial distribution: "radial" refers to a horizontal direction with a lens center as a center; in a central region of the lens, the at least two micro/nano structure sets are distributed relatively densely and uniformly to ensure central vision clarity; toward an edge region, the distribution gradually becomes sparser, and shapes and sizes of the at least two micro/nano structure sets are slightly adjusted to compensate for aberrations caused by edge refraction; and

wherein a defocus amount De of each of the at least two micro/nano structure sets satisfies: +4.00 D ≤ De ≤ +10.00 D, wherein D represents diopters, and +10.00 D is an extreme defocus; each of the gradient microlenses reaches the extreme defocus within a field angle of 8°; and the defocus amount of each of the at least two micro/nano structure sets is positively correlated with the field angle, such that the defocus amount increases as the field angle increases, and an effective defocus amount in a micro/nano-structure region is larger.