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APPARATUS AND METHOD FOR LASER BEAM SPLITTING

FIELD OF INVENTION

5 This invention deals with laser beam splitting which may be used, for example, in laser texturing, laser micro-etching, laser micro-fabrication, optical recording and other laser applications.

BACKGROUND OF THE INVENTION

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In many laser applications, for example, laser texturing, if a laser beam can be split into multi beams and the intensities and pitches among the beams are precisely adjustable, the efficiency will be multiplied. However, current splitting devices are unsuitable for this purpose. A polarizing beam splitter plate and cube can be used to split an incident beam into a reflected
15 beam and a transmitted beam and the energy (power) ratio is adjustable by rotating the polarization plane of the incident beam. However, realignment of two beams, precise adjustment of separation and angular separation between the split beams are quite complicated. For a non-polarizing beam splitter plate and cube, the energy (power) ratio depends on the device tolerance and is not adjustable. A mask projection system can be used
20 to obtain multi beams but there are several disadvantages: the intensity distribution among the beams depending on the uniformity of the incident beam and mask is not adjustable; the separation between the beams depends on the mask pattern and is difficult to adjust. US patents 4565426, 5671047, which concern laser beam splitters, are unsuitable also due to lack of adjustability.

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OBJECT OF THE INVENTION

It is an object of this invention to provide an apparatus and method for splitting a laser beam into two beams for which the energy balance, separation and angular separation from each
30 other are finely adjustable. Since the split beams remain Gaussian they may be precisely

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controlled and transmitted so close to each other that they can pass along substantially the same optical path to allow for focussing by a single optical element.

SUMMARY OF THE INVENTION

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In accordance with the invention, there is provided an apparatus for laser beam splitting, having a waveplate for polarizing an incident beam and a first birefringent wedge for splitting the polarised beam into two orthogonally polarized split beams, characterised in that the birefringent wedge is rotatable about its optical axis to vary an angle of incidence of the polarised beam on the wedge so as to allow for controlled adjustment of a separation angle between the split beams.

Preferably, the optical axis is parallel to a deflection surface of the wedge and is substantially perpendicular to the incident beam.

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Preferably, the apparatus includes a second birefringent wedge arranged such that the split beams are incident thereon and are transmitted therethrough to reduce the separation angle between the split beams.

20 In another aspect, there is provided a method of laser beam splitting including polarising an incident beam utilising a waveplate and splitting the beam into two orthogonally polarised split beams with a birefringent wedge, characterised by rotation of the birefringent wedge about its optical axis to vary an angle of incidence of the polarised beam on the wedge to thereby control adjustment of a separation angle between the split beams.

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BRIEF DESCRIPTION OF THE DRAWINGS

The invention is more fully described, by way of non-limiting example only, with reference to the drawings, in which:

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Figure 1 is a schematic diagram of an apparatus used for splitting a linearly-polarized laser beam into two linearly-polarized laser beams in which two birefringent wedges are used;

Figure 2 is a schematic diagram of an apparatus used for splitting a linearly-polarized laser beam into two linearly-polarized laser beams in which only one birefringent wedge is used;

Figure 3 shows the separation of two split beams as a function of laser incident angle on the first birefringent wedge surface; and

Figure 4 shows the pitch between two focused spots of split beams as a function of laser incident angle on the first birefringent wedge surface in an apparatus of the invention.

EXPLANATION OF SYMBOLS

Features shown in the drawings are indicated using the following references:

1: a half waveplate or a quarter waveplate

2: the first birefringent wedge

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3: the second birefringent wedge

4: a focus lens

25 5: laser beam incident angle on the first wedge surface

6: wedge angle of the first wedge

7: wedge angle of the second wedge

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- 8: angular separation between two split beams transmitted through total device
- 9: pitch between two focussed spots of the split beams
- 5 10: incident linearly-polarized laser beam
- 11: transmitted laser beam through waveplate
- 12: upper split beam through the first wedge
- 10 13: down split beam through the first wedge
- 14: transmitted beam of beam 13 through the second wedge
- 15 15: transmitted beam of beam 12 through the second wedge
- 16: separation between two split beams transmitted through the first wedge
- 17: direction of the optical axis of the first wedge which is perpendicular to the paper surface
- 20 18: direction of the optical axis of the second wedge which is perpendicular to the paper surface or in both the paper surface and its own incident surface.

DETAILED DESCRIPTION

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Figure 1 shows a schematic diagram of a first embodiment of an apparatus used for laser beam splitting in accordance with the invention.

As shown in Figure 1, waveplate 1, which can be either a half waveplate or a quarter
30 waveplate, is perpendicular to the incident beam 10 and can be rotated precisely around it.

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The optical axes of both birefringent "V"-shaped wedges 2,3 are parallel to their deflection surfaces respectively. The first wedge 2 can be rotated precisely around its own optical axis, which is perpendicular to the incident laser beam 10. The optical axis of the second wedge 3 is perpendicular to the incident beam 10 and parallel or perpendicular to the optical axis of the first wedge 2 and placed upside-down with the first birefringent wedge 2.

The linearly-polarized laser beam 10 passes through the waveplate 1. If it is a half waveplate, the transmitted laser beam 11 remains linearly-polarized but its polarization plane is precisely rotated to the direction which is 45° away from the optical axis of the first wedge 2. If it is a quarter waveplate, the transmitted beam 11 becomes almost a perfect circularly-polarized beam by rotating the waveplate precisely. Since there are two diffraction indexes in the birefringent wedge, the beam 11 transmitted through the first wedge 2 is split into two beams 12 and 13 having balanced energy and mutually orthogonal polarization planes. The separation 16 between the beams 12 and 13 depends on the beam incident angle 5 of the beam 11 on the first wedge 2, the wedge angle 6 and the wedge's thickness. The angular separation between the beams 12 and 13 depends on the incident angle 5 and the wedge angle 6. The second wedge 3, which has a slightly smaller wedge angle 7 than that of the first wedge and is placed upside-down with the first wedge, is used to compensate the angular separation between the beams 12 and 13. The angular separation 8 between the beams 14 and 15 transmitted through the total device becomes precise and sensitive to the incident angle 5. The separation between the beams 14 and 15 only has a little change comparing with the separation 16 because the incident angles of the beams 12 and 13 on the second wedge 3 are quite small. The beams 14 and 15 are so close to each other that they can pass through other optical components just like a single beam. If a focus lens 4 is used to focus them, two focused spots can be obtained. These two spots have same size and intensity and the pitch between them is equal to the angular separation 8 multiplied by the focal length of the focus lens 4. The pitch can be precisely adjusted by changing the incident angle 5 of the beam 11.

In another embodiment, only one birefringent wedge is used if the required pitch between the two focused spots is relatively large and the adjustment range of the pitch is relatively small.

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Such an arrangement is shown in Figure 2. The meanings of the symbols are the same as in Figure 1.

One more case is that the device can be used as a serial order to get four, eight, or multiple
5 focused spots with identical feature.

As an example, a set of design parameters of a practical device using in laser texture machine are presented as follows:

10 Similar to the components shown in Figure 1, a half waveplate and two calcite wedges are used. Two wedges have the same thickness of 6mm on their smaller edge and their optical axes are parallel to their deflection surfaces respectively and parallel to each other. The incident angle of the beam on the deflection surface of the first wedge may be varied between 0° and 15° . The wedge angle of the first wedge is $2^\circ 51' 0'' \pm 10''$. The wedge angle of the
15 second wedge is $2^\circ 48' 20'' \pm 10''$. The separation between the split beams transmitted through the first calcite wedge as a function of the incident beam angle on it is shown in Figure 3. If a focus lens with a focal length of 51 mm is used to focus the split beams transmitted through the total device, the pitch between the two focused spots as a function of the laser beam incident angle on the first wedge is shown in Figure 4.

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Besides the calcite wedges mentioned above, all other birefringent wedges, such as quartz wedge, are also suitable for this invention.

Besides laser texture mentioned above, the apparatus and method of this invention can be used
25 in many laser applications, such as laser micro-etching, laser micro-fabrication, laser micro-processing and optical recording.

In summary, the laser beam splitter has the following effects and advantages

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When a linearly-polarized laser beam is incident into the laser beam splitter, the waveplate rotates the polarization plane of the incident beam to the direction which is 45° away from the optical axis of the first wedge or transfers the incident beam into a circularly-polarized beam. Then the birefringent wedge splits it into two beams having balanced energy, mutually
5 orthogonal polarization planes and adjustable angular separation. The second birefringent wedge is used to compensate the angular separation of the split beams in case the required angular separation has to be precisely and sensitively adjustable. The pitch between two focused spots is equal to the angular separation between the split beams multiplying by the focal length of the focus lens.

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Furthermore, embodiments of the invention have the following advantages. The device is compact and easy to control and the method is simple. The split beams are so close to each other that they can pass through the follow-up optical components just like a single beam and this will simplify the optical system. The energy balance and the pitch between the focused
15 spots of the split beams are finely adjustable. The device can be used in a serial order to get four, eight or more multiple beams.

CLAIMS

1. Apparatus for laser beam splitting, having a waveplate for polarizing an incident beam and a first birefringent wedge for splitting the polarised beam into two
5 orthogonally polarized split beams, characterised in that the birefringent wedge is rotatable about its optical axis to vary an angle of incidence of the polarised beam on the wedge so as to allow for controlled adjustment of a separation angle between the split beams, and the apparatus further including a second birefringent wedge arranged such that the split beams are incident thereon and are transmitted therethrough to reduce the
10 separation angle between the split beams, wherein the second wedge is arranged so as to produce anisotropic affects on the transmitted beams, for substantially cancelling anisotropic effects produced by the first birefringent wedge .
2. Apparatus as claimed in claim 1, wherein the optical axis is parallel to a
15 deflection surface of the wedge and is substantially perpendicular to the incident beam.
3. Apparatus as claimed in claim 1, wherein the second birefringent wedge has an optical axis substantially parallel to a deflection surface thereof, and substantially parallel or perpendicular to the optical axis of the first birefringent wedge whilst being
20 substantially perpendicular to the incident beam.
4. Apparatus as claimed in any one of claims 1 to 3, wherein the wedges are substantially "V"-shaped in profile and inverted relative to each other.
- 25 5. An apparatus as claimed in any one of the preceding claims, wherein the waveplate is either a half waveplate or a quarter waveplate.
6. An apparatus as claimed in any one of the preceding claims, wherein the waveplate is substantially perpendicular to the incident beam and is rotatable about the
30 beam.
7. A method of laser beam splitting including polarising an incident beam utilising a

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5 waveplate and splitting the beam into two orthogonally polarised split beams with a birefringent wedge, characterised by rotation of the birefringent wedge about its optical axis to vary an angle of incidence of the polarised beam on the wedge to thereby control adjustment of a separation angle between the split beams wherein the waveplate is arranged to polarize the incident beam by 45° away from the optical axis of the birefringent wedge.

8. A method as claimed in claim 7, wherein the waveplate is arranged to circularly polarize the incident beam.

10 9. A method as claimed in claims 7 or 8, wherein a second birefringent wedge is provided and arranged such that the split beams are incident thereon for transmission therethrough, the second birefringent wedge serving to reduce the angle of separation between the split beams.

15 10. Apparatus for laser beam splitting, having a waveplate for polarizing an incident beam and a first birefringent wedge for splitting the polarised beam into two orthogonally polarized split beams, characterised in that the birefringent wedge is rotatable about its optical axis to vary an angle of incidence of the polarised beam on the wedge so as to allow for controlled adjustment of a separation angle between the split beams, wherein the waveplate is either a half waveplate or a quarter waveplate.

20 11. Apparatus as claimed in claim 10, wherein the optical axis is parallel to a deflection surface of the wedge and is substantially perpendicular to the incident beam.

25 12. Apparatus as claimed in claim 10 or 11, including a second birefringent wedge arranged such that the split beams are incident thereon and are transmitted therethrough to reduce the separation angle between the split beams.

30 13. Apparatus as claimed in claim 12, wherein the second wedge is arranged so as to produce anisotropic effects on the transmitted beams, for substantially cancelling anisotropic effects produced by the first birefringent wedge.

14. Apparatus as claimed in claim 12 or 13, wherein the second birefringent wedge has an optical axis substantially parallel to a deflection surface thereof, and substantially parallel or perpendicular to the optical axis of the first birefringent wedge whilst being substantially perpendicular to the incident beam.

15. Apparatus as claimed in any one of claims 11 to 13, wherein the wedges are substantially "V"-shaped in profile and inverted relative to each other.

16. An apparatus as claimed in any one of the preceding claims 10 to 15, wherein the waveplate is substantially perpendicular to the incident beam and is rotatable about the beam.

17. A method of laser beam splitting including polarising an incident beam utilising a waveplate and splitting the beam into two orthogonally polarised split beams with a birefringent wedge, characterised by rotation of the birefringent wedge about its optical axis to vary an angle of incidence of the polarised beam on the wedge to thereby control adjustment of a separation angle between the split beams, wherein the waveplate is arranged to circularly polarize the incident beam.

18. A method as claimed in claims 17, wherein a second birefringent wedge is provided and arranged such that the split beams are incident thereon for transmission therethrough, the second birefringent wedge serving to reduce the angle of separation between the split beams.

19. Apparatus for laser beam splitting, having a waveplate for polarizing an incident beam and a first birefringent wedge for splitting the polarised beam into two orthogonally polarized split beams, characterised in that the birefringent wedge is rotatable about its optical axis to vary an angle of incidence of the polarised beam on the wedge so as to allow for controlled adjustment of a separation angle between the split beams, wherein the waveplate is substantially perpendicular to the incident beam and is rotatable about the beam.

20. Apparatus as claimed in claim 19, wherein the optical axis is parallel to a deflection surface of the wedge and is substantially perpendicular to the incident beam.

5 21. Apparatus as claimed in claim 19 or 20, including a second birefringent wedge arranged such that the split beams are incident thereon and are transmitted therethrough to reduce the separation angle between the split beams.

10 22. Apparatus as claimed in claim 21, wherein the second wedge is arranged so as to produce anisotropic effects on the transmitted beams, for substantially cancelling anisotropic effects produced by the first birefringent wedge.

15 23. Apparatus as claimed in claim 21 or 22, wherein the second birefringent wedge has an optical axis substantially parallel to a deflection surface thereof, and substantially parallel or perpendicular to the optical axis of the first birefringent wedge whilst being substantially perpendicular to the incident beam.

20 24. Apparatus as claimed in any one of claims 21 to 23, wherein the wedges are substantially "V"-shaped in profile and inverted relative to each other.

25 25. A method of laser beam splitting including polarising an incident beam utilising a waveplate and splitting the beam into two orthogonally polarised split beams with a birefringent wedge, characterised by rotation of the birefringent wedge about its optical axis to vary an angle of incidence of the polarised beam on the wedge to thereby control adjustment of a separation angle between the split beams, wherein the waveplate is arranged to circularly polarize the incident beam.