ARRANGEMENT FOR IMAGING MULTIPLE ARRAYS OF LIGHT BEAMS

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ABSTRACT

Apparatus for combining information beams by using a space variant mirror in the context of free space optical switching and computing, where light beams comprise beamlets that are focused onto surfaces to form arrays of light spots. Beam combining is achieved by positioning the space variant mirror to coincide with the plane on which the spots are focused, and to thereby allow one beam to pass through the space variant mirror without loss and another beam to be reflected off the space variant mirror, also without loss.

12 Claims, 4 Drawing Sheets
ARRANGEMENT FOR IMAGING MULTIPLE ARRAYS OF LIGHT BEAMS

This application is a continuation of application Ser. No. 07/248,468, filed on Sep. 23, 1988, now abandoned.

BACKGROUND OF THE INVENTION

Harnessing the bandwidth of optics for transmission of information and for computing is very much at the forefront of current research and development efforts. This includes work in the area of "free space" optics, where the three-dimensional space (formerly referred to as "ether") is the communication medium between light emitting devices and light detecting devices. One advantageous characteristic of "free space" is that light beams can be intersected without collimating. Another advantageous characteristic is that a large number of beams can be handled in parallel, as a group, with a single optical setup. Still another advantage is that "free space" is indeed free; it does not need to be manufactured, and it costs nothing.

On the other hand, optics imposes its own constraints on the architecture of the systems that are designed. These constraints have been overcome to some extent, as exemplified by systems described, for example, in U.S. patent application Ser. No. 071,105, filed Jul. 8, 1987, and titled "Computational Origami", and in U.S. patent application Ser. No. 219,623 filed Jul. 15, 1988, and titled "Optical Crossover Network". These and other free space systems have one thing in common, and that is the use of plane arrays of optical devices, and corresponding arrays of light beams. Typically also, a number of different beam arrays are required because a usable logic device will, in general, need at least two logical inputs. Depending on the type of device, it may also require one or more optical bias beams. This is akin to a transistor logic gate, where one employs a number of logic signals and a power supply source for operating the logic gate. Hence, there is a need in the field of free space optical information handling to operate with a plurality of beams and, in particular, is a need to arrange for multiple arrays of beams, with each array being derived possibly from a different source or sources, to be incident on a desired array of optical devices. In other words, there is a need to combine beams and to separate beams.

On approach for combining or separating two beam arrays is to apply them to a beam splitter as shown, for example, in FIG. 1. Beam 11 is applied to cube beam splitter 10 at one face of the beam splitter, where it is split into beams 13 and 14. Beam 12 is applied to beam splitter 10 at another face of the splitter (orthogonal to the first face), where it is split into beams 15 and 16. Beams 14 and 15 exit beam splitter 10 at the same face (to the right) and thus they are combined. Alas, using simple beam splitters to achieve beam combining entails loss, since energy is diverted to beams 13 and 16.

Polarization-dependent beam splitters can also be used to combine two beams, and such combining is achieved essentially but without loss. In the arrangement of FIG. 1 where the beam splitter is sensitive to the polarization mode of the incoming light, it can be arranged for the light of beam 11 to be so polarized that it passes through the beam splitter without deflection, thus placing no energy in beam 13. Similarly, it can be arranged for the light of beam 12 to be so polarized that it is deflected in the beam splitter, thus placing no energy in beam 16. The resultant beam combining that occurs within beam splitter 10 is lossless, but the combined beam is partially polarized in one mode and partially polarized in another mode.

Dichroic beam splitters can be used, in principle, to combine beams of different wavelengths without loss. In practice, however, we may not wish to be constrained to use different wavelengths for the different beams, and devices may not work if such different wavelengths are used.

In a different environment, and for a different purpose, image combining has been accomplished with the use of a reflective grating. This approach is described in "Real Time Incoherent Optical-Electronic Image Subtraction," Dashew et al., Optics Communications, Jun., 1973, pp. 105-108. The described approach passes one image through a reflective grating and reflects another image through the same grating. The gratings in effect samples both images. The combined sample images are then applied to an image plane where the sampled combined image is converted to electronic signals and processed. This is akin to sampling a signal at a high rate (above Nyquist rate), combining the sampled signals, and filtering with an appropriate bandpass filter. Of course, there is loss associated with this approach because a portion of each image is missing. In fact, in its operation (vis-a-vis loss) the Dashew et al. arrangement is identical the arrangement of FIG. 1, but optically more complex.

SUMMARY OF THE INVENTION

This invention overcomes the drawbacks of prior art methods of combining information beams by using a space variant mirror in a new manner. More specifically, in the context of free space optical switching and computing, where light beams comprise beamlets that are focused onto surfaces to form arrays of light spots, this invention combines beams by appropriately positioning the space variant mirror to coincide with the plane on which the spots are focused. No loss occurs with this method of beam combining because the mirror is positioned with its reflected areas situated at the beam waists of the reflected array of beamlets (in each of the three dimensions) and, concurrently, the mirror is also positioned with its transmissive areas situated at the beam waists of the transmitted array of beamlets.

In one preferred embodiment the space variant 90° mirror is placed at an angle other than 90° with respect to the center axis of the beam that is transmitted through the mirror. The beam that is reflected is then appropriately arranged with respect to that center axis to combine the reflected beam with the transmitted beam to form a single beam that is applied to the image collection optics. Advantageously, the angle of the mirror with respect to that center axis is as close to 90° as practical, and the beams (both the transmissive and the reflective beams) are arranged to be very weakly divergent.

In another preferred embodiment, a beam splitter is used to permit the reflective beam to be arranged perpendicularly to the transmissive beam. In this arrangement, the beam splitter is interposed between the reflective beam and the mirror, and the mirror is situated perpendicularly to the center axis of the transmissive beam. The beam splitter reflects the reflective beam onto the space variant mirror.

To avoid losses associated with the beam splitter, a still another embodiment employs a beam splitter that is
sensitive to the polarization of light. The reflective beam is then arranged to be polarized in the mode that causes deflection in the beam splitter. To provide for a combined beam that is uniformly polarized, a quarter wave plate is placed between the beam splitter and the mirror, and the transmissive beam is arranged to have a circular polarization mode. The resulting combined beam passes through the quarter wave plate and the beam splitter without deflection, possessing a polarization mode that is orthogonal to the polarization mode of the incoming reflective beam.

**BRIEF DESCRIPTION OF THE DRAWING**

FIG. 1 shows a prior art approach to beam combining:

FIG. 2 shows the arrangement of light spots from two beam arrays that form the input to an optical logic array;

FIG. 3 depicts one realization for a beam splitter in accordance with the principles of our invention;

FIGS. 4 and 5 illustrate enhanced embodiments of the realization presented in FIG. 3;

FIG. 6 shows the use of our invention to combine more than two beams;

FIG. 7 presents a realization of our invention that employs a beam splitter; and

FIG. 8 illustrates a realization of our invention for combining three beams with the aid of one beam splitter.

**DETAILED DESCRIPTION**

FIG. 2 depicts a possible arrangement where the principles of this invention can be utilized. Rectangle 20 represents a surface that contains optical logic elements 21, such as SEED devices. It is desired to apply to each logic element 21 two light spots, such as 22 and 23. Rectangle 25 represents the surface of light emitting devices 26. This can be a structure on there is placed an array of LED, a source of light spots derived from a single laser beam, etc. Devices 26 correspond in number and relative position to light spots 22 of rectangle 20. It is realized, of course, that magnification and reduction are possible, but for purposes of this description and for the sake of simplicity, a magnification factor of 1 is assumed. Rectangle 27 represents another surface of light emitting devices 28, and these devices correspond to light spots 23 of rectangle 20. It may be noted that in FIG. 2 light sources 28 have a positional orientation within rectangle 27 that is slightly shifted to the left when compared to the positional orientation of elements 26 in rectangle 25. This shift corresponds to the separation between light spots 22 and 23 in rectangle 20. In an actual realization, however, it is likely that the entire array (the rectangle and its associated light sources) would be shifted.

What is necessary to accomplish is the combining of light source 26 and light source 28 and to apply the combined energy onto rectangle 20.

FIG. 3 depicts one arrangement in accordance with the principles of this invention. In FIG. 3, light sources from rectangle 25 pass through an appropriate focusing lens to result in beam 35 that focuses an array of spots onto a plane indicated by dashed line 36. Similarly, light sources from rectangle 27 pass through an appropriate focusing lens and result in beam 37 that focuses an array of spots onto a plane represented by dashed line 38. Mirror 24 is a thin glass plate on which reflective areas 29 are deposited. The front view of mirror 24 is shown in FIG. 2. It may be noted that the reflective areas of mirror 24 for the FIG. 3 arrangement are elliptical, with the major axis being \( \sqrt{2} \) times the mirror axis. This accounts for the tilt of the mirror with respect to reflected beam 37. As arranged in FIG. 3, the light of beam 35 passes entirely through the transmissive portion of mirror 24 while the light of beam 37 is reflected in its entirety off reflective areas 29 of mirror 24. Also as arranged in FIG. 3, beam 37 is approximately at right angles to beam 35 and mirror 24 is approximately an angle of 45° with respect to the center axis (24) of beam 35. That is, mirror 24 is an angle that is half the angle between the center axes of beams 35 and 37. The light transmitted through mirror 24, combined with the light reflected off mirror 24, is applied to focusing lens 40. Lens 40 focuses light spots 22 and 23 onto plane 20.

From FIG. 3 it is readily apparent that beams 35 and 37 must be very weakly converging because the waist of the beamlets of beam 35 do not all coincide in space with the transmissive portions of mirror 24. The waists are at plane 36, while the mirror is at a different plane (that is, at a 45° angle thereto). Correspondingly, the waists of the beamlets of beam 37 (at plane 38) also do not all coincide with the reflective areas of mirror 24. Use of beams 35 and 37 that are not very weakly converging would result in two problems. First, with respect to beam 35, some light might not be transmitted (when it expands to cover more than the transmissive portion of the mirror) and the loss of light, when it occurs, would increase with the distance away from the center axis of beam 35. With respect to beam 37, light might also be lost when the beam is wider than the reflective portion and, additionally, crosstalk can occur when the energy of one spot is comingle on the reflective portions of mirror 24 with the energy of another spot.

FIG. 4 illustrates an optical setup that minimizes the above problem. In FIG. 4, beam 37 is situated at an angle \( \theta \) with respect to the center axis of beam 35 that is as close to 180° as is possible, and mirror 24 is situated at the angle \( \theta/2 \).

FIG. 5 depicts an arrangement that is similar to the arrangement of FIG. 4, but it includes field lenses 41 and 42. Lenses 41 and 42 image the pupil of the source onto the pupil of the objective, which permit lens 40 to have a smaller diameter.

FIG. 6 presents an optical arrangement modeled after FIG. 3 that may be employed when more than two beams are to be combined. In essence, mirror 43 combines beams 44 and 45, to form combined beam 46, and mirror 47 combines beams 46 and beam 48. A focusing relay lens 49 is placed between mirror 43 and mirror 47 and field lenses 50, 51 and 52 can also be included. The principles employed in FIG. 6 can easily be extended to a large number of beams to be combined. As an aside, it may be observed that the spatial arrangement of mirror 47 is different from that of mirror 43, with the former most likely having more transmissive areas than the latter.

Mirrors such as the ones described above, with arbitrary patterns of reflective and transmissive regions, can be fabricated by conventional lithographic techniques. In a conventional approach, for example, a metallic reflective coating is deposited on a glass substrate, and photoresist is applied to the substrate. The photoresist is then exposed in the usual manner with the appropriate pattern from a lithographic mask, etched away to expose the areas of metal to be removed, and the metal is
The first stage is to perform an initial search of the document. This involves using a text-matching algorithm to identify potential keywords or phrases that may be relevant to the question. Once the initial search is complete, the second stage is to refine the search results. This involves using more advanced analysis techniques to narrow down the list of potential keywords or phrases to those that are most relevant to the question. The third and final stage is to present the information in a clear and concise manner. This involves using data visualization tools to create charts and graphs that help to illustrate the key points of the analysis. The resulting report can then be used to answer the question or to inform policy decisions.
beam waists is interposed between said applied second energy beam and said mirror.

6. The beam combiner/splitter according to claim 1 wherein said means responsive to said first plurality of beams comprises a lens interposed between said first plurality of beams and said mirror, and wherein said means for focusing said second plurality of beams comprises a lens interposed between said second plurality of beams and said mirror.

7. The beam combiner/splitter according to claim 1 wherein said first surface intersects said second surface within the space of said mirror.

8. A beam combiner/splitter characterized by means responsive to an applied first plurality of energy beams for forming a first pattern of beam waists at a first surface and a first corresponding pattern of energy spots at a working surface;

means responsive to an applied second plurality of energy beams for forming a second pattern of beam waists at a second surface and for forming a second corresponding pattern of energy spots at said working surface; and

a mirror at said working surface having a collection of reflective areas and transmissive areas, with said reflective areas arranged to coincide with said first corresponding pattern and said transmissive areas arranged to coincide with said second corresponding pattern, said mirror thus passing essentially all of the energy of said second corresponding pattern of energy spots through said transmissive areas and reflecting essentially all of said first corresponding pattern of energy spots off said reflective areas, and further comprising:

means for combining and focusing said first pattern of beam waists reflected off said mirror and said second pattern of beam waists passed through said mirror to form a third pattern of waists at a third surface;

means responsive to an applied third energy beam for forming a fourth pattern of waists at a fourth surface; and

a second mirror having a collection of reflective areas and transmissive areas, with said reflective areas arranged to coincide with said third pattern and said transmissive areas arranged to coincide with said fourth pattern, and said mirror thus reflecting said fourth pattern of beam waists off said reflective areas and passing said third pattern of beam waists through said transmissive areas.

9. An apparatus comprising:

a beam splitter for receiving energy from a first direction, delivering at least a portion of said energy to a second direction, and for receiving energy from said second direction;

a mirror, positioned perpendicularly to said second direction, that includes a collection of reflective areas and transmissive areas wherein said beam splitter directs light that is received from said first direction to said second direction, when the light from the first direction is polarized in a first mode and directs light that is received from said second direction to a third direction, when the light from the second direction is polarized orthogonally to said first mode; and further comprising quarter-wave plate between said beam splitter and said mirror.

10. An apparatus comprising:

a beam splitter for receiving a first plurality of energy beams from a first direction, delivering at least a portion of said energy to a second direction, and for receiving energy from said second direction;

a mirror that includes a collection of reflective areas and transmissive areas, that is positioned perpendicularly to said second direction and adapted to reflect energy delivered by said beam splitter to said second direction;

means for focusing essentially all of the energy delivered by said beam splitter to said second direction onto said reflective areas of said mirror to cause the energy so focused to reflect off said mirror and reenter said beam splitter; and

means for focusing essentially all of the energy of a second plurality of energy beams received from said second direction onto said transmissive areas of said mirror to cause the energy so focused to pass through said mirror and enter said beam splitter.

11. The apparatus of claim 10 wherein said means for focusing comprises a lens interposed between said beam splitter and said mirror.

12. An optical apparatus comprising:

first means responsive to a first plurality of beams for developing a first array of energy spots at a working surface;

second means responsive to a second plurality of beams for developing a second array of energy spots at said working surface, with the energy spots of said second array being incongruent with the energy spots of said first array; and

a mirror at said working surface having a collection of reflective areas and transmissive areas, with said reflective areas arranged to encompass the energy spots of said first array, and said reflective areas arranged to encompass the energy spots of said second array.