OPTICAL BEAM STEERING SWITCHING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of and claims priority from commonly assigned co-pending application Ser. No. 09/536,164, filed Mar. 25, 2000. This application is related to the following copending U.S. provisional applications, all of which are herein incorporated by reference: "Two-Dimensional Gimbaled Scanning Actuator with Vertical Electrostatic Comb-Drive for Actuation and/or Sensing" of Behrang Behin, Michael J. Daneman, Meng-Hsiang Kiang, Kam-Yin Lau, and Satinderpall Pannu, serial number 60/191,987, filed Mar. 24, 2000; and "Self-Aligned Comb-Drive Actuators" of Behrang Behin and Satinderpall Pannu, serial number 60/191,856, filed Mar. 24, 2000; and "Multi-Layer, Self-Aligned Vertical Comb-Drive Electrostatic Actuators and Fabrication Methods" of Behrang Behin and Satinderpall Pannu, serial number 60/192,097, filed Mar. 24, 2000.

FIELD OF THE INVENTION

This invention relates generally to fiber optic communications. More particularly, the invention relates to optical switches for N×N arrays of fibers.

BACKGROUND ART

Modern fiber optical communications systems direct optical signals over multiple fibers. Such systems require optical switches to direct light beams from any given fiber in an input fiber array to any given fiber in an output array. One class of optical switches uses an approach called beam steering. In beam steering, the light from the fiber is selectively deflected or steered by one or more movable optical element from the input fiber to the output fiber. Suitable optical elements include microelectromechanical system (MEMS) mirrors. MEMS mirrors are usually actuated by magnetic interaction, electrostatic, or piezoelectric interaction. Typically, two sets of moveable mirrors are used to steer the beam. Each fiber has a small "acceptance window". The fiber only efficiently couples light that is incident within a narrow range of angles and positions. Although a single mirror will generally direct the beam from an input fiber to the correct output fiber, two mirrors ensure that the light beam enters the output fiber at the correct angle. If the beam makes too large an angle with the axis of the fiber, light from the beam will not couple properly to the fiber, i.e. there will be high losses.

Optical switches using the steering-beam approach have been demonstrated in two primary implementations. The first uses linear arrays of mirrors with a single angular degree of freedom. Combining two such mirror arrays as shown in FIG. **1** allows an implementation of an N×N optical switch, where the number of input and output channels is equal to the number of mirrors in each array. The first array steers an optical beam from an input fiber to the appropriate mirror on the second array, which then steers the beam into the corresponding output fiber. This implementation uses simple single-axis mirrors; however, it is limited in its scalability since the optical path between fibers becomes unreasonably large for large port counts (e.g. >32×32), increasing the loss of the switch

The second implementation depicted in FIG. **2** uses two sets of 2-dimensional mirror arrays, each mirror having two angular degrees of freedom. The input and output fibers are each also arranged in a 2-dimensional grid with the same dimension as the mirror arrays. The mirrors in the first mirror array steer the optical beams from the fibers onto the appropriate mirror in the second mirror array which then steers the beam into the corresponding fiber. This approach is considerably more scalable, since, due to its 2-dimensional layout, the size of the mirror and fiber arrays grows as the square root of the number of input/output ports, which is much slower than in the case of a 1-dimensional grid. Therefore, switches with much larger port count (>2000×2000) are possible. However, this implementation requires the mirrors to rotate about two different axes. Such mirrors are considerably more difficult to design, fabricate, and control.

There is a need, therefore, for a beam steering apparatus that uses single axis optical elements to switch optical signals in an N×N fiber array.

OBJECTS AND ADVANTAGES

Accordingly, it is a primary object of the present invention to provide a beam steering system that uses single axis optical elements. It is a further object of the invention to provide a beam steering system wherein ability to switch a particular path is independent of the current configuration of the switch

SUMMARY

These objects and advantages are attained by a beam steering module. The steering module generally comprises first and second N×N arrays of single axis mirrors. The mirrors in the first array rotate about a particular axis (X-axis) while the mirrors in the second array rotate about an axis different from the first axis (Y-axis). Relay optics disposed between the two arrays image the first mirror array onto the second mirror array such that the beam angle may be controlled with respect to both the X and Y-axes by adjusting the angle of the appropriate mirrors in the first and second mirror grids. The relay optics preserve at an image plane an angle of emergence with respect to an object plane. The relay optics typically comprise a confocal arrangement of lenses.

Two steering modules may be combined to form a beam steering system. With two modules, it is possible to completely determine, at the plane of the output fiber grid, the position and angle of an optical beam emerging from any of the input fibers.

Embodiments of the steering modules of the present invention may be used to selectively couple light from an input fiber in an N×N input fiber array to any output fiber in an N×N output fiber array.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** depicts a one-dimensional beam steering apparatus according to the prior art;

FIG. **2** depicts an isometric view of a two-dimensional beam steering apparatus according to the prior art;

FIG. **3** depicts an isometric view of a beam steering apparatus according to a first embodiment of the present invention; and

FIGS. **4** depicts an isometric view of a beam steering apparatus according to a second embodiment of the present invention;

DETAILED DESCRIPTION

Although the following detailed description contains many specifics for the purposes of illustration, anyone of